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EXPLORATIONS IN THE PATTERNING OF STIMULI CONDITIONED TO THE G.S.R.[1]

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The stimuli involved in the conditioning which occurs in most life situations are almost always highly complex. Moreover, both observation and theoretical considerations lead to the view that in many, if not most, such situations the subject reacts to the combination or pattern of complex stimuli, and scarcely at all to the separate components or to any simple summation effects arising from the separate components. In contrast to this the results from the ordinary conditioned reaction experiments employing simple compound stimuli, such as a light and a buzzer presented simultaneously, seem to indicate that reactions are evoked according to the principle of simple physiological summation; *i.e.*, the compound stimulus as a whole will evoke the reaction conditioned but the separate components of the compound will also evoke the reaction, though somewhat less vigorously. Pavlov (**6**) has reported the experimental production of conditioned stimulus patterns in dogs by means of differential reinforcement—systematic reinforcement of the compound and extinction of the components. As always with Pavlov, these experiments were on a qualitative level; *i.e.*, in spite of the fact that he measured the salivary flow, there was no quantitative index of the extent of patterning. The present paper reports an

[1] The writer is greatly indebted to Miss Ruth Hays who acted as technician throughout the present investigation. Dr. Stanley B. Williams computed the statistical reliabilities.

exploratory attempt at the development of such an index in connection with the pattern conditioning of the galvanic skin reaction in man.

The index of the extent of patterning chosen for a try-out was the ratio of the arithmetical sum of the amplitude of the reaction to two stimulus elements, each presented on a separate occasion, to the amplitude of the reaction to their simultaneous presentation. For example: The stimuli employed were a weak light from a flash-light bulb in a darkened compartment, and a mild cutaneous vibration. The reaction employed was the galvanic skin reaction produced originally by an electric shock. In one experiment the light and the vibrator as a simultaneous stimulus complex were conditioned to the shock. Soon after conditioning the two stimuli when presented together gave a mean amplitude of galvanic reaction (R_{l+v}) of 3.3 units, whereas the light alone (R_l) gave 2.5 units and the vibrator alone (R_v) gave 2.9 units. Thus,

$$\frac{R_l + R_v}{R_{l+v}} \tag{1}$$

(*i.e.*, $\frac{2.5 + 2.9}{3.3}$ or 1.63) was the index employed. Suppose, now, that pattern conditioning were to begin. It is to be expected that the amplitude of reaction evoked by each of the separate stimulus components (R_l and R_v) will progressively diminish so that their total, which makes up the numerator of the fraction, will progressively approach zero. This, of course, would reduce the ratio itself from 1.63 to something in the neighborhood of zero. On the other hand, one or both of the stimulus elements might be systematically reinforced and the combination systematically extinguished. In this case the index would presumably shift in an opposite direction, increasing toward infinity. So much for the general concept of patterning and the index by which it was proposed to trace the progress of its development.

The subjects employed in the investigation were young men registered in Yale University. They were paid by the hour for their services. They were seated in a comfortable Morris chair over the top of which had been built a kind of hood which, when the subject was seated, could be closed so that his head and torso were in darkness. The light has been described above. The cutaneous vibrator has been described

elsewhere (1); it was attached to the back of the subject's forearm in a vertical position so that the freely moving core of the cylindrical magnet rested through gravity upon the skin. The vibrator was actuated by a 60-cycle A.C. current stepped down by a toy transformer giving 120 complete vibrations per second. The intensity of the vibratory stimulus, while mild, was easily felt. Both the light and the vibrator lasted for approximately one-half second (l = .485 sec and v = .509 sec). About a third of a second (.342 sec) after the beginning of the buzzer and the light, an A.C. shock was administered to the subject's wrist; this lasted for .08 sec. The shock was adjusted in conference with each subject at an intensity which approached the maximum that he could tolerate. The subjects wore earphones which delivered a continuous A.C. roar sufficiently loud to screen out effectively any sounds of the apparatus. The galvanic skin reaction was picked up by two silver 25-cent coins bound to the palm of the subject's hand by sponge rubber and a leather strap. A wall type of Leeds and Northrup galvanometer was employed, which was sufficiently sensitive to require on most occasions considerable resistance in the circuit to prevent the beam of light from swinging off the scale when stimuli were given. It was necessary to vary this resistance from time to time in order to secure readable records. However, it was never varied during the presentation of any test cycle (balanced unit of test trials), so that no constant errors were introduced into the process by this procedure. Under these conditions the absolute readings were of little significance, and no significance is given them in this report. The movements of the light were followed by a manually operated pointer whose movements were recorded by a connected stylus on the waxed paper of a polygraph.

Preliminary Experiments (A and B)

At the outset of the investigation it was thought desirable to determine something concerning the characteristics of the patterning index by trying it out first in a strictly unpatterned situation. It was suspected in advance that factors other than patterning might influence the magnitude of the index. For example, the denominator (R_{l+v}) presumably represents a physiological summation of the excitatory potentials of the light and the vibrator. Now, on the plausible assumption that two excitatory potentials will summate physiologically to produce this reaction more or less according to the so-called growth or exponential function,[2] the physiological sum of two such potentials would be considerably less than their arith-

[2] An example of such a function is the following:

$$R_l = A - Ae^{-hS}$$

where S represents the number of units of stimulation, A represents the physiological limit of reaction amplitude, e is a mathematical constant, and h is an empirical constant. Peak (5) and Hovland (2) among others have shown summation effects of this general nature.

metical sum—specifically,

$$R_{l+v} = R_l + R_v - \frac{R_l R_v}{A} \qquad (2)$$

where A is the physiological limit (4). It may be shown from this equation that the patterning ratio, quite apart from any patterning whatever, will diminish as the values of R_l and R_v diminish with respect to the value of the physiological limit (A). Thus, suppose that originally $R_l = 6$, $R_v = 9$, and $A = 10$. Suppose, further, that through a process of systematic experimental extinction without patterning, the values were diminished until $R_l = 2$ and $R_v = 3$. Substituting the original set of values in equation (2), we have,

$$R_{l+v} = 6 + 9 - \frac{54}{10} = 9.6.$$

Substituting the 9.6 in formula (1), we have as the original index,

$$\frac{6 + 9}{9.6} = 1.56.$$

Taking, now, the extinction values and substituting them in equation (2), we have,

$$R_{l+v} = 2 + 3 - \frac{6}{10} = 4.4.$$

Substituting the 4.4 in formula (1) we have as the index after extinction,

$$\frac{2 + 3}{4.4} = 1.14.$$

This diminution in the value of the index from 1.56 to 1.14 thus represents an artifact and not any increase in the extent of patterning.

Experiment A. The Influence of the Impartial Extinction of Unpatterned Stimuli on the Pattern Index

In order to test this hypothesis and at the same time find out something of the size of the ratio for quite unpatterned stimuli, an experiment was set up in which the stimuli were not conditioned at all but were merely 'sensitized.' This was done by simply shocking the subjects 20 times in the apparatus

on the first day at about 2-minute intervals. The four following days were test days during which the light, the vibrator, and the combination of light and vibrator together were presented in double fatigue order a number of times with an equal number of mere shocks interspersed among the test trials. Under these conditions both the light and the vibrator, as well as the combination, evoked fairly vigorous sensitization reactions, or 'alpha' conditioned reactions as they are sometimes called (**3**, p. 431). Eight subjects were employed.

The detailed stimulation sequences employed in this experiment for the several subjects were as follows:

Key to symbols

L = reinforcement of light alone.
V = reinforcement of vibrator alone.
C = reinforcement of compound stimulus (light and vibrator presented simultaneously).
l = unreinforced presentation of light.
v = unreinforced presentation of vibrator.
c = unreinforced presentation of compound.
S = presentation of shock alone.

Subjects 1, 2, 3, and 4

Sensitization Day	*c*	*l*	*v*	*c*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Test day I	*S*	*S*	*S*	*S*	*c*	*l*	*v*	*c*	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*							
" " II	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*	*S*	*S*	*S*	*S*	*c*	*l*	*v*	*c*							
" " III	*S*	*S*	*S*	*S*	*c*	*l*	*v*	*c*	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*							
" " IV	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*	*S*	*S*	*S*	*S*	*c*	*l*	*v*	*c*							

Subjects 5, 6, 7, and 8

Sensitization Day	*c*	*v*	*l*	*c*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Test day I	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*	*S*	*S*	*S*	*S*	*c*	*v*	*l*	*c*							
" " II	*S*	*S*	*S*	*S*	*c*	*v*	*l*	*c*	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*							
" " III	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*	*S*	*S*	*S*	*S*	*c*	*v*	*l*	*c*							
" " IV	*S*	*S*	*S*	*S*	*c*	*v*	*l*	*c*	*S*	*S*	*S*	*S*	*v*	*c*	*c*	*l*							

The combination of *c l v c* of Test Day I of Subjects 1, 2, 3, and 4 is what was spoken of above as a *test cycle*.

The indices for the four test days from the pooled results are shown in Fig. 1.[3] There it is seen that the index begins

[3] This pooling was performed as follows: The mean amplitude score was computed for each subject for *v*, *l*, and *c* separately. From these means a mean for the group as a whole was computed for *v*, for *l*, and for *c* respectively. From these latter means an index value was computed by substituting the three means in formula 1. This general procedure was followed in the determination of all the index values appearing in all the graphic representations contained in the present report.

at 2.29 on Test Day I, and falls to a value of 1.36 on Test Day IV. This is exactly in line with theoretical expectation, since the progressive extinction which, incidentally, came at regular intervals easily anticipated by the subjects, would almost certainly reduce the galvanic reactions through the four test

FIG. 1. Graph showing the ratio $(R_l + R_v) \div R_{l+v}$ for galvanic skin reactions evoked by strictly unpatterned stimuli as the reactions involved are undergoing experimental extinction (Experiment A).

days. The mean index of the first two test days was found to be 23 percent greater than that of the second two test days. The critical ratio of the difference to its standard error, neglecting correlation, was, however, only .97.[4]

[4] In an attempt to secure some rough indication of the dependability of the differences between certain contrasting index values secured in the manner described in footnote 3, the following procedure was employed: Separate indices were computed for each subject from the means of his *v*-, *l*-, and *c*-amplitude scores; the means of these indices, the standard errors of these means, and the standard error of the differences between such contrasted means were then computed, $n - 1$ being used in the computation of the standard errors. Where correlation coefficients were involved they were found to be small and erratic; they were disregarded in the computation of the standard error of differences between means. In general the distribution of the indices of individual subjects showed as much indication of normality to inspection as usually

We may note also that the index under these conditions begins at about its maximum, which according to our present understanding cannot, except through sampling errors, exceed a value of 2.00. According to the same understanding the index, except as patterning enters the situation, cannot fall below 1.00.

Experiment B. The Influence of Differential Reinforcement During the Process of Testing on the Pattern Index

In this experiment on the first day there were given at about 2-minute intervals, 10 reinforcements of the light and, after a 10-minute pause, 10 reinforcements of the vibrator. The following four days were given over to combined reinforcement and testing the three elements in the situation; each day in balanced order the light and the vibrator were each reinforced 4 times, the light and the vibrator were each tested twice, and the stimulus complex was tested 4 times, all *tests* of course without reinforcement. Thus, incidental to the testing process, differential reinforcement was given the components as against the stimulus complex. The various factors in the situation were balanced with care by the same type of procedures shown in detail in the description of Experiment A. Eight subjects were employed; they were divided into four groups.

The values of the index are shown graphically in Fig. 2. There is a suggestion of a rise in the index as the testing progresses, though this is not consistent. In this connection it is to be noticed that at the beginning of the testing period there has been no differential reinforcement but that during the process of testing differential reinforcement is given. And since this is a reinforcement of the components, the index should rise unless over-ridden by the tendency, already noted, for the index to diminish during testing. Pooling the first and the second two days in order to secure larger statistical

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are shown by similarly small samples of ordinary data. However, because of the suspicion with which statisticians usually regard means of ratios, the statistical reliabilities contained in this paper may be disregarded by those readers who share this suspicion.

samples, it was found that the mean index of the second two days was 10 percent greater than that of the first two days. The critical ratio of this difference to its standard error was, however, only .61. Nevertheless, there is a suggestion in the

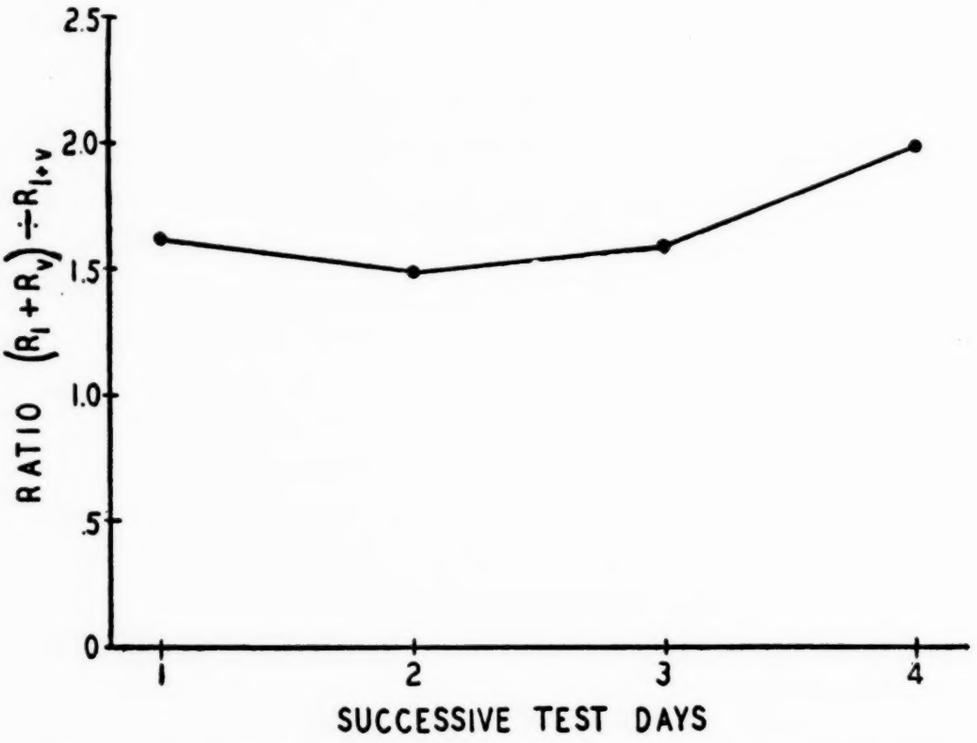

FIG. 2. The value of the ratio $(R_l + R_v) \div R_{l+v}$ for the galvanic skin reaction evoked by stimuli where the components of the complex are reinforced during the process of testing but the stimulus complex as a whole has not been so reinforced (Experiment B).

graph that the patterning resulting from the differential reinforcement incidental to the testing process has been dominant over any weakening tendency to reduce the ratio noticed in the preceding experiment.

INFLUENCE ON THE INDEX OF CONTRASTED PATTERNING BY DIFFERENTIAL REINFORCEMENT (*C* AND *D*)

The problem of this portion of the investigation was to study the effect of differential reinforcement of a stimulus complex upon the patterning index, $\frac{R_l + R_v}{R_{l+v}}$. Since no dependable standard or norm for a zero amount of patterning is

known, it was decided to run two groups of subjects in which the direction of the patterning training was reversed so that each, in a sense, might serve as a control experiment for the other.

Experiment C. Stimulus Complex Differentially Reinforced

Procedure.—In this experiment the compound stimulus ($l + v$) was reinforced 10 times at random for each of four days. Among these reinforcements occurred the pre-arranged random unreinforced presentations of 10 light stimuli and 10 vibrator stimuli. The fifth, sixth, and seventh days were given over to testing the relative strength of the three types of stimuli with no reinforcements whatever; *i.e.*, each day the light, the vibrator, and the combination of light and vibrator were each presented 12 times in a balanced order, all without reinforcement exactly as in Experiment A. Eight subjects were employed.

Experiment D. Stimulus Components Differentially Reinforced

Procedure.—In this experiment the first four days were devoted to the reinforcement of the light and the vibrator, 5 times each. Interspersed among these reinforcements in a pre-arranged random order were 20 unreinforced presentations of the stimulus complex consisting of the simultaneous presentation of the light and the buzzer. The three following days were devoted to testing the strength of the three types of stimulation exactly as in Experiment A; *i.e.*, without reinforcement to any of them. The various factors likely to cause constant errors were balanced with care in Experiments C and D by methods analogous to those described in detail for Experiment A.

Results

The contrasting results of these two experiments are presented in Fig. 3. There it may be seen that in spite of some inconsistency there is a fairly marked tendency for Experiment C, where the stimulus complex received differential reinforcement, to manifest a lower index value than that of Experiment D, where the stimulus components received differential rein-

forcement, exactly as the principle of differential reinforcement would lead us to expect. In order to secure an indication of the statistical reliability of the difference suggested by this graph, the data for all three days were pooled and the mean patterning index was found for each group. This revealed an index difference between the means of the two groups of 15 percent, with a critical ratio, based on the standard error, of 1.68; which means that there is only about one chance in 20 that there is not a difference of some size in the direction here

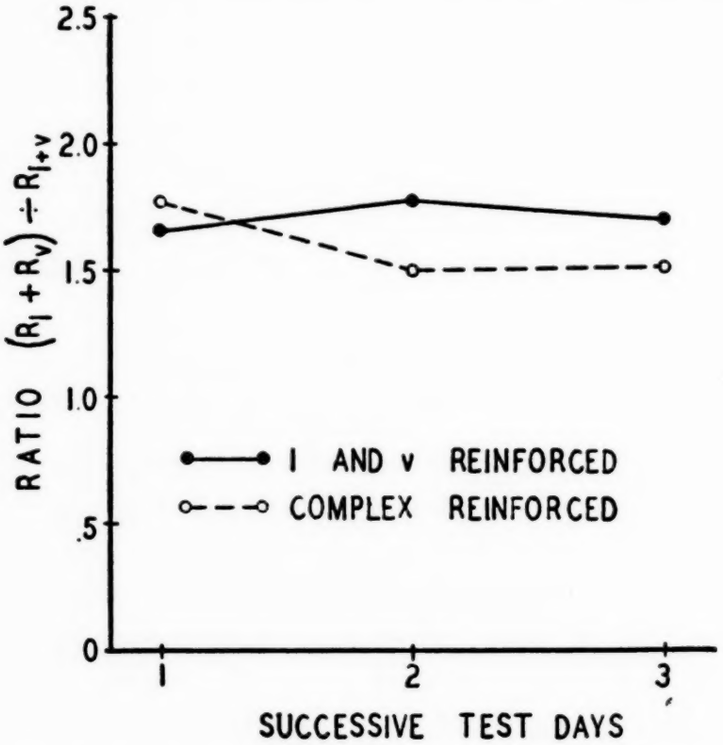

FIG. 3. Graphs showing the ratio $(R_l + R_v) \div R_{l+v}$ for two situations, patterned by differential reinforcement, one in which the components were systematically reinforced and the combination systematically extinguished, and the other in which this process was reversed (Experiments C and D).

indicated. There is thus a fairly clear indication of patterning as a result of the differential reinforcement here employed, though it is a little surprising that it is not more marked.

Because these test days were not complicated by any reinforcement whatever, they offer an opportunity for the patterning index to manifest the fall to be expected on theoretical grounds and suggested by Preliminary Experiment A. Accordingly the results of both groups of subjects were pooled for the first 18 stimulations, and separately for the second 18

stimulations of each test day. The results of this arrangement of the data are shown in Fig. 4. There it may be seen that despite some inconsistencies there is a marked suggestion for the second half of the stimulations of each day to give the smaller index, quite as expected. A pooling of all three days reveals a mean difference of 8 percent with a critical ratio,

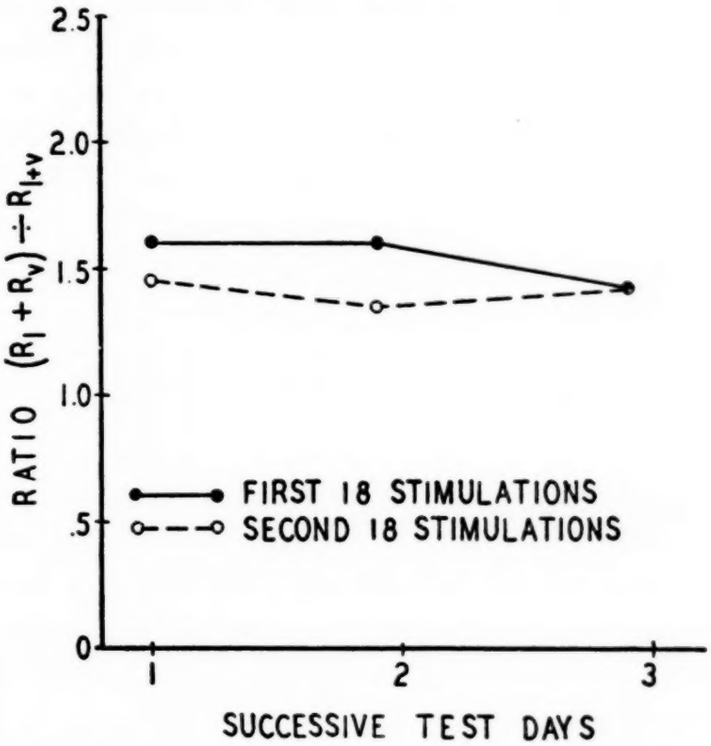

FIG. 4. Comparative values of the ratio $(R_l + R_v) \div R_{l+v}$ for the first and second 18 stimulations on each testing day. The onset of experimental extinction presumably accounts for the lowered ratio values at the second 18 stimulations (Experiments C and D).

based on the standard error, of 1.09. This means that there is a chance of a little less than 9 in 10 that the difference observed is genuine. However, these results, with the support of the independent evidence of Preliminary Experiment A, give a support to the hypothesis definitely in excess of the statistical reliability shown by either study separately.

DOES SPONTANEOUS PATTERNING OCCUR IN ORDINARY CONDITIONING?

It is a matter of very considerable biological importance whether or not complex conditioned stimuli become patterned to a certain extent by the ordinary process of conditioning

when no differential reinforcement occurs. This problem gave rise to Experiment E.

Experiment E. The Influence of Intensive Conditioning of the Stimulus Complex Without Differential Reinforcement

This is the most elaborate experiment of the series, extending over a period of 19 experimental periods. The procedure was, first, to condition the subjects to the stimulus complex by 20 reinforcements on Day I, and to test on each of the next four days the reaction amplitude evoked by the light and the vibrator twice each and the stimulus complex four times, 14 reinforcements of the complex being distributed symmetrically throughout the period. Four test days for one of the typical groups of subjects were as follows:

Test day	I	*C C C C C*	*c l*	*C C C*	*l c*	*C C C*	*c v*	*C C C*	*v c*
"	II	*C C C C C*	*v c*	*C C C*	*c v*	*C C C*	*l c*	*C C C*	*c l*
"	III	*C C C C C*	*c v*	*C C C*	*v c*	*C C C*	*c l*	*C C C*	*l c*
"	IV	*C C C C C*	*l c*	*C C C*	*c l*	*C C C*	*v c*	*C C C*	*c v*

Then followed 10 days of uninterrupted reinforcement of the stimulus complex as on Day I, in the hope that it might produce some spontaneous patterning. In order to test for this possibility the 10 days of intensive conditioning of the stimulus complex were followed by 4 more days exactly like Test Days I to IV already described.

The results of this experiment are shown graphically in Fig. 5. There it may be seen at a glance that the now familiar downward tendency of the index, with continued testing and its incidental extinction effects, appears in both pre- and post-training test days. By pooling the results of the first and second two days it was determined that the mean of the first two days was 12 percent greater than that of the second. The ratio of this difference to its standard error, neglecting correlation, was found to be 1.62.

Secondly, it is evident that post-training tests yield values, upon the whole, *higher* than do the pre-training tests. This, of course, is exactly opposite what would be produced by any spontaneous patterning which might result from the 10 days of intensive conditioning of the stimulus complex. By pooling the data from the first four test days and those from the second

four test days separately, it was found that the mean of the first test days exceeded that of the second test days by 13 percent. The ratio of this difference to its standard error is 1.83.

This raises the question as to why this observed result should have occurred, because something more than mere failure of spontaneous patterning would be required to produce such an effect. The statistical reliability of the difference found shows that it may have resulted from mere limitation

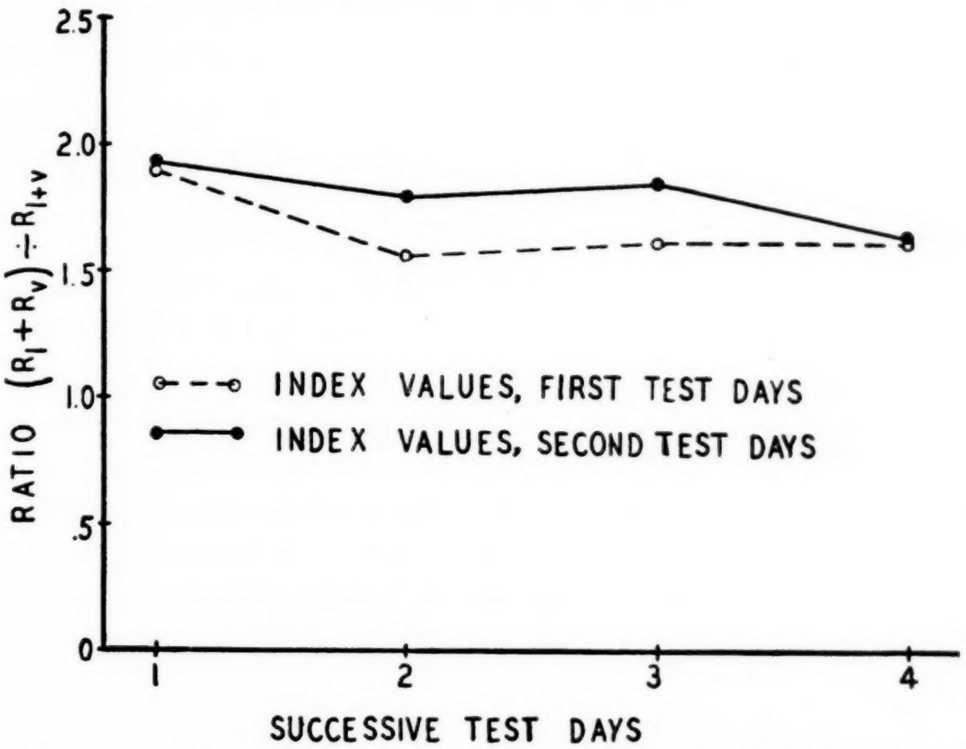

FIG. 5. Graph showing comparative values of the ratio $(R_l + R_r) \div R_{l+r}$ for galvanic skin reaction from tests preceding and following 10 days of intensive conditioning without differential reinforcement (Experiment E).

of the data sample. However, it is to be expected that the extinction incidental to the testing would influence the relatively weakly reinforced excitatory potentials involved during the first tests, more than those resulting from 10 additional days of reinforcement. This may account for the generally lower position of the values obtained on the first group of 4 testing days. It is possible, of course, that this factor may have obscured a tendency to patterning even on the first testing day. If so the tendency to spontaneous patterning must have been weak.

Summary and Conclusions

An explorational investigation of the process of patterning stimuli conditioned to the galvanic skin reaction in man has been carried out involving five experiments and 40 subjects. The two most conspicuous outcomes emerging from the investigation are the small amount of patterning of the galvanic skin reaction in man which results from specific Pavlovian differential reinforcement, and the instability of the index $\frac{R_l + R_v}{R_{l+v}}$. It is possible that autonomically controlled reactions such as the G.S.R. are not so readily conditioned specifically to patterns as is behavior involving the striated muscles. There is need for a determination of the progress of stimulus patterning in free animal behavior uncomplicated by the presence of accessory symbolic (speech) behavior.

But before effective research can be conducted in this field, an index of patterning must be devised which is not subject to the gross distortions characteristic of $\frac{R_l + R_v}{R_{l+v}}$ as shown by the present investigation. The present index may fall approximately to a value of 1.00 from mere feeble conditioning, or from extinction effects. Values between 1.00 and zero may thus serve as indicators of gross patterning effects, but weaker effects are undetectable and stronger effects are quantitatively distorted.

A possible means of correcting for this distortion of the index here employed is suggested:

1. Condition a sizable group of subjects to the two components of a compound stimulus, measuring the absolute amplitude of their conditioned reactions to the components separately and to the compound stimulus, at several stages of both the conditioning and the subsequent extinction process.

2. From these data compute the ratio of the mean amplitude of reaction of the stimulus component evoking the larger reaction, to that evoked by the other component. Let this ratio be represented by B, in which case $B > 1$.

3. From these same data compute the value of A, the presumptive physiological limit, at a number of different stages

of training and extinction by means of equation (2) above, which now takes the form,

$$A = \frac{R_l R_v}{R_l - R_v - R_{l+v}}. \tag{3}$$

If the A-values so computed should vary systematically in some direction the indication would be that equation (2), as well as the exponential equation shown in footnote 2 from which equation (2) is derived, does not represent the situation and others should be tried until one is found which gives constant values for A within the limits of experimental error.

4. Then, with several sizable additional squads of subjects, proceed to set up a variety of learning situations in which patterning is suspected to occur, using as the index of patterning the revised formula,

$$\frac{R_l + R_v}{R_l' + R_v'} \tag{4}$$

where R_l and R_v are empirical values obtained from the data suspected of being patterned. R_l' and R_v', on the other hand, are values corresponding to R_l and R_v respectively, but computed from the empirical R_{l+v} of the same situation suspected of being patterned.

The derivation of the R_l' and the R_v' is as follows:

Let x = the component whose reaction has the larger amplitude, and Bx = the component whose reaction has the smaller amplitude. Substituting these values in equation (2), we have,

$$R_{l+v} = x + Bx - \frac{x(Bx)}{A}.$$

Clearing of fractions and collecting terms, we have the quadratic expression,

$$x^2B - xA(1 + B) + AR_{l+v} = 0. \tag{5}$$

From this equation may be obtained the amplitude value of both components (R_l' and R_v'), since the values of both A and B were determined by the first portion of the experiment and that of R_{l+v} by the situation suspected of having its stimuli

patterned. We now have all the data necessary to substitute in the revised pattern formula (4). This formula should, within the limits of experimental error, yield a value of 1.00 for unpatterned situations and any deviations from this not due to sampling limitations should indicate some form of patterning. Unfortunately, because of the relative nature of the data, the above formulae cannot be applied to the results of the present investigation.

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THE EFFECTS OF INTRODUCING IDEATIONAL ELEMENTS IN PERCEPTUAL-MOTOR LEARNING[1]

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Introduction

Comparatively little experimental work has been done toward determining the effect of ideational elements in the context of a patterned motor performance during the learning process. Whereas the effect of various forms of motor articulation upon the learning of ideational material has been frequently investigated, it is comparatively more difficult to find studies that have been designed particularly for the purpose of answering the question: Can a patterned motor performance be learned as economically without the aid of ideational elements, or when these have been reduced to a minimum, as when such ideational elements are present in the context of the motor pattern to be learned?

A study by Warden (**10**) seems to be one of the earliest to have any bearing on the problem. Having analyzed the methods of learning used by his subjects, he reports that "the word reaction method proved by far the most economical employed, requiring on the average less than one-fourth as many trials for complete mastery as the motor reaction method, and approximately one-half as many trials as the so-called visual imagery method." Husband (**6**), comparing the same methods in a maze learning experiment found that the motor method was inefficient whereas the counting method was the most superior. Lambert and Ewert (**7**) showed that increasing the instructions resulted in greater efficiency of learning the stylus maze.

The frequently quoted results of the studies by McGeoch and Melton (**9**) and again by McGeoch (**8**) on the relative

[1] Subject for doctorate thesis at the University of North Dakota under the direction of Dr. C. W. Telford.

retention values of motor and ideational materials do not apply here directly since their use of the saving scores made it unnecessary for them to use equally difficult materials. Likewise the related study of Freeman and Abernethy (**2**) has no direct application to the present study because ideational elements seem to have been present in both of their learning contexts. Nevertheless the results of this study should have a bearing on their conclusions.

Among the more recent studies on the effect of ideational context on motor learning is one by Davis (**1**). He found that the learning of the serial-verbal and the visual-image subjects was superior to that of the kinesthetic-tactual. Honzik (**5**) concluded that "learning on the basis of kinesthesis alone is impossible and unnecessary although well-learned motor habits may have incorporated a large kinesthetic element which seems to be essential to the smooth running of a movement pattern." He states, however, that this function of kinesthesis is assumed only after learning has begun in conjunction with other classes of stimulation. Probably the most recent and the last studies reported are those by Hilgard and Humphreys (**4**) and Hilgard, Campbell and Sears (**3**) who have found that verbalization is an aid in learning to make discriminatory responses in conditioning.

The importance of these studies becomes evident when one considers the potential effect of various types of imagery, symbolization and verbalization on the acquisition of laboratory techniques and skills. The problem isolated for investigation here is to study the effect of introducing three different simple ideational elements in the learning of a comparatively simple patterned motor performance. The task consisted of learning to light a series of twelve lights under four conditions: (1) When no extraneous ideational elements were associated with the lights and when perceptual elements, it was hoped, were kept at a minimum; (2) when digits, 1 2 3 4 5 6, corresponding with the position of the lights were presented with the lights; (3) when a related series of letters, A B C D E F, in corresponding order was presented with the lights; (4) when an unrelated series of letters, B Q R F L Z, was presented with

each light. For the sake of brevity, these conditions will hereafter be designated as Blk (blank), 1–2, AB, and BQ. Care was exercised to make the motor response patterns as simple as possible so that the perceptual element might be at a minimum during the Blk condition. A further precaution was to develop through preliminary experimentation four motor response patterns that would be of approximately equal difficulty.

Apparatus and Procedure

The nature of the experiment required an exposure apparatus on which four serial motor problems with a variation in ideational context could be presented, learned and reproduced.

The essential and principal piece of apparatus, therefore, consisted of a box divided into six compartments. Each compartment contained one six-volt bulb. A three-quarter inch hole had been drilled directly above each light in the top of the box. A groove cut the entire length of the box permitted a strip of glass to be placed over these openings and to be slid across them longitudinally. The glass was ground on the under surface, but left smooth on top where the ideational materials had been painted. A board which held the glass in its groove also served to cover the materials that were not to be exposed at any particular time. The strip of glass could be moved into any one of four positions shown in Fig. 1.

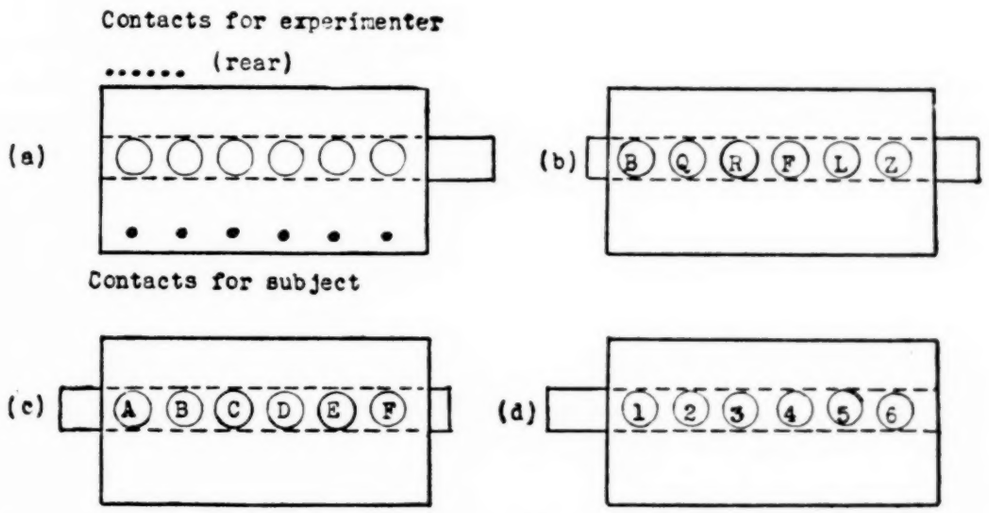

Fig. 1. Top view of exposure apparatus with (*a*) blank context, Blk; (*b*) unrelated letters, BQ; (*c*) related letters, AB; (*d*) digits, 1–2.

The positions of the two separate sets of contact points through which the lamps were lighted by the experimenter and the subject respectively from the rear and from the front of the box are also indicated in Fig. 1. The subject's performance consisted in lighting the lamps in the order given by the experimenter through touching these contact points with a stylus held in the subject's preferred hand.

A seven-pen polygraph was used to insure accuracy in counting the number of trials and the time required by the subject. Since six of the pens were wired in parallel with the lamps, the order of the individual lamps lighted by either experimenter or subject were also recorded, thus indicating the errors. The seventh pen was operated electrically through a pendulum and recorded time intervals in seconds.

The experimenter made individual appointments with subjects. The subject was conducted into an individual laboratory and seated in front of the exposure apparatus placed on a typewriting table. He was given the stylus and instructed how to light the lamps. He was then given a short practice series consisting of four series of five items each. During the practice series the independent variables were rotated in the same order in which they were to be used for that particular subject. The stimuli were presented at a constant rate of one per second and the duration of each stimulus presented was approximately one half of a second.

The serial exposure method of learning was used: the experimenter repeated the serial order in which the lamps were to be lighted and the subject attempted to reproduce this order after each presentation. The patterned motor response was considered learned when the subject was able to light the series of lamps correctly three times in succession without error.

Each series consisted of twelve items. Four such series had been designed by using some of the six lamps consecutively. Preliminary experimentation resulted in the construction of such series which showed no significant difference in difficulty. Space will not allow a description of these new series in detail. The use of four such series with each subject permitted the learning of one under each of the Blk, 1–2, AB, and BQ conditions. Since four series include 24 permutations, 48 subjects selected at random from a class in general psychology were used so that the four series were rotated altogether twice. Furthermore, the Blk, 1–2, AB, and BQ contexts were rotated against the four different series.

Incidental data obtained with the last twenty-four subjects consisted (1) of measuring the retention values of the various materials by the relearning method immediately after each subject had met the learning criterion, (2) of giving five speed tests to each subject, and (3) of obtaining a report from the subject on which method they preferred for learning and which method they used during the speed test.

Results and Discussion

The results of the experiment are discussed under the following topics: (1) order of the conditions of exposure from the most advantageous to the least; (2) the average number of errors per response, the average length of trials, and the average number of seconds per error under each of the learning conditions.

An examination of the means and simple index numbers in Table I indicates that the order of the materials from the most advantageous to the least is 1–2, BQ, AB, and Blk. This comparison shows that the patterned motor performance was most readily learned with the digits and least readily with

the blank spaces over the lights. Furthermore, the means agree in the order named with respect to trials, time and errors. The index numbers tend to emphasize the extent of this agreement and to facilitate the making of these comparisons.

With 1–2 being the most favorable condition for learning and Blk the least, it is of interest to note that the unrelated letters compare almost equally favorably with the digits. There is a surprisingly close correspondence between the means of the variables 1–2 and BQ with respect to all three criteria, trials, time and errors. In view of this, the contrast between

TABLE I

ARRANGEMENT OF TYPES OF MATERIAL FROM MOST ADVANTAGEOUS TO LEAST

Advantage	from Most	Less	Less	to Least
Types	1–2	BQ	AB	Blk
Trials:				
Mean	4.5	4.7	5.6	7.0
PE_m*	0.17	0.18	0.32	0.42
CR: M/PE_m	26.5	26.1	17.5	16.7
Index	100.	104.4	124.4	155.6
Time:				
Mean	107.	110.	132.	159.
PE_m	4.7	4.3	9.1	10.7
CR	22.8	25.6	14.5	14.8
Index	100.	102.8	123.4	148.6
Errors:				
Mean	21.	22.	26.	34.
PE_m	1.3	1.3	1.5	2.7
CR	16.2	16.9	17.3	12.6
Index	100.	104.8	123.8	161.9

* $PE = .6745\,\sigma/\sqrt{N}$.

these two ideational elements and Blk, in which the ideational elements were reduced to a minimum, is all the more noticeable. The means for trials in 1–2 and BQ were 4.5 and 4.7 respectively whereas the mean for Blk is 7.0. Corresponding differences are to be seen in the means for time and errors.

The mean differences are summarized in Table II. Only two reliable differences by the criterion of four times the probable error occur, namely, between Blk on the one hand and the two most effective ideational forms, BQ and 1–2, on the other. These differences are reliable with respect to trials,

time and errors. A comparison of the most favorable of the ideational materials, BQ and 1–2, shows no reliable difference on the basis of the same criteria of learning.

The introduction of the AB element during the learning process resulted in a mean which lies approximately at one-third of the distance between the means from 1–2 to Blk. Thus, the mean of 5.6 for the number of trials with the AB material occupies roughly a two-sevenths position of this distance while the means for AB with respect to time and errors

TABLE II

MEAN DIFFERENCES AND PROBABILITY THAT TRUE DIFFERENCES ARE GREATER THAN ZERO

Comparisons:	Blk–12	Blk–AB	Blk–BQ	12–AB	12–BQ	AB–BQ
Most Advantageous:	1–2	AB	BQ	1–2	1–2	BQ
Trials:						
D	2.5	1.4	2.3	1.1	0.2	0.9
PE_D*	0.45	0.53	0.46	0.36	0.25	0.37
CR : D/PE_D	5.6	2.6	5.0	3.1	0.8	2.4
Probability	1.00	.96	1.00	.98	.71	.95
Time:						
D	52.	27.	49.	25.	3.	22.
PE_D	11.7	14.0	11.5	10.2	6.4	10.1
CR_D	4.4	1.9	4.3	2.4	0.47	2.2
Probability	1.00	.90	1.00	.95	.62	.93
Errors:						
D	13.	8.	12.	5.	1.	4.
PE_D	3.0	3.1	3.0	2.0	1.8	2.0
CR_D	4.3	2.6	4.0	2.5	0.6	2.0
Probability	1.00	.96	1.00	.95	.66	.91

* $PE_D = \sqrt{\overline{PE}^2_{M.1} + \overline{PE}^2_{M.2}}$.

occupy approximately a three-fifths and a one-third position respectively. Hence it would seem that learning with the AB material exposed over the lights more nearly resembles that of the other two ideational forms, 1–2 and BQ, than it does that of the Blk.

The AB mean shows no clearly defined position between those of either of the above extremes. There is no reliable difference between AB and Blk on the one hand, nor between AB and the other two ideational elements, 1–2 and BQ, on the other. Nevertheless, the difference between Blk and AB

in terms of trials, time and errors is always greater than the difference between AB and either one of the remaining ideational forms. In other words, the difference between Blk and all of the ideational forms is always greater than the intra-differences between any ideational forms, and when Blk is compared with the most advantageous of the ideational aids, there is a statistically reliable difference.

The question of why the related letters, AB, did not function equally well as ideational aids must be left unanswered at the present. The author knows of no experimental evidence which would satisfactorily account for the apparent difficulty that some subjects experienced when this ideational material was presented during the learning process.

From the foregoing observations it would seem safe to generalize that it takes longer to learn a patterned motor performance when ideational elements have been reduced to a minimum. The introduction of ideational elements, therefore, facilitates learning at least in the early stages of the learning process. This is in general agreement with all of the results cited in the introductory section although the experimental procedures used in the present study were independently designed in order to emphasize particularly the influence of relatively simple and controlled ideational contexts in what was thought to be also a relatively simple motor pattern.

Before continuing with further analysis, it should be stated that this generalization appears to have some bearing on the problems of relative retention of motor and ideational learning studied by McGeoch (**8**) and Freeman and Abernethy (**2**). The results of the present study support McGeoch's contention that motor habits not only require more trials for learning but also are more time consuming and more subject to errors. Since in the experiment of this study, four comparable patterned motor performances were learned under three ideational and one minimum-ideational condition, there can be little question as to the greater number of trials and time that subjects require and the greater amount of practice they receive during the learning process with the latter. In a later section

an attempt will be made to show that this greater amount of practice is probably due to the initial greater number of errors.

Measurements of retention for immediate recall showed that the largest saving score, 39, was obtained with the Blk. The saving scores for AB, BQ, and 1–2 in corresponding order are 35, 30, 23. It will be noticed that the advantage indicated by the saving scores is altogether the inverse of that in learning. Although the differences in saving scores are seemingly small, the inverse order of these scores lends support to the contention that relative retention is a function of practice. Since this experiment was originally planned to test the relative difficulty of learning under the conditions named, it was impossible to obtain data on delayed recall.

Before closing this section, it should be mentioned that among nineteen subjects who reported the method of learning they preferred, 47 per cent preferred the 1–2 condition, 26 per cent the AB, 11 per cent the BQ and 16 per cent the Blk. There is agreement between the preferences shown by subjects with regard to the 1–2 and Blk condition. Yet there is a general discrepancy between their choices and the method by which they actually did learn most effectively. This is indicated in the original data omitted here for lack of space. In this connection it is also to be recalled that experimentally there was no choice between the introduction of the unrelated letters and the digits as optional conditions for learning. Both of them facilitated learning to an approximately equal degree. Yet the subjects did not show this in the preferences stated by them. As a matter of fact AB was the second most preferred form although it did not function as advantageously as did the BQ material. It is apparent that subjects failed here to recognize their most effective methods of learning.

Finally it might be said that exceptions occurred in the matter of best learning. While there are probably some intrinsic factors present in the materials which would account for the advantages of one method over the other, these alone are not the only factors. As a matter of fact, 9 per cent of the 48 subjects learned most readily by the Blk method, 24 per cent by the AB method, 31 per cent by the 1–2 method and 36

per cent by the BQ method. In another analysis of data omitted here, it was shown that if the number of trials were limited to two, one could expect 21 per cent and 15 per cent of the subjects to have completed their learning respectively under the 1–2 and AB conditions whereas only 6 per cent would have completed their learning under each of the other methods, Blk and BQ. But if the trials were limited to 8 trials, 96 per cent would have completed their learning by the BQ method, 90 per cent by the AB method and the 1–2 method and 79 per cent by the Blk. In ten trials 100 per cent would have learned by the BQ method, 96 per cent by the 1–2 method, 92 per cent by the AB method and 88 per cent by the method of Blk. A similar analysis of errors and time gave comparable results. This would caution us to interpret the means given in Table I with some leniency and prevent us from assuming that there are only intrinsic factors of materials. That is to say, while the materials themselves may result in differences, these differences are perhaps minimized through the previous learning habits of the subjects as well as possible intrinsic factors of the patterned motor performance.

Regarding learning habits, there are two interesting types of reports made by several subjects. One of them is that in trying to learn the Blk, a few subjects tried to use some sort of numbering or alphabetical system, or even looked at the center of the lights and tried to remember them as -3, -2, -1, 1, 2, 3. These subjects report that it seemed difficult to associate their ideational aids in some such manner and that after they had become confused, they finally learned them by "position" without reference to any ideational system. The other is that in attempting to do the motor patterns as fast as possible, many of them reported "not thinking" of the ideational materials associated with the patterns and having discarded them. Instead they just "felt a sort of rhythm" in the pattern. This would seem to indicate that the intrinsic imagery in learning motor habits is probably some sort of rhythmical-spatial imagery (possibly the kinesthetic-tactual method of Davis, 1) without visual imagery. As such, this might be assumed to be an intrinsic factor in the pattern of

the motor performance itself to be distinguished from intrinsic factors in the accompanying ideational materials. Perhaps this is equivalent to writing a definition of "myothesis" or so-called imageless thought, as well as the neurological engram concept.

There are three other interesting comparisons that can be obtained from Table I: (1) the average number of errors per response, (2) the average length of trial, and (3) the average number of seconds per error. These findings are summarized in Table III.

The average number of errors per trial is practically the same under all conditions, being 4.7 for both 1–2 and BQ, 4.6 for AB, and 4.9 for Blk. The greatest number of errors occurred with Blk. That a greater number of errors did occur under the Blk condition seems less important at the moment

TABLE III

ERRORS PER RESPONSE (E/R), LENGTH OF RESPONSE (R), SECONDS PER ERROR (T/E)

Type	E/R	R	T/E
1–2	4.7	12.8	5.10
BQ	4.7	12.4	5.00
AB	4.6	12.6	5.08
Blk	4.9	11.7	4.68

than the fact that the relationship between the average number of errors and the average number of trials is fairly constant. On the basis of this approximately constant relationship, one might assume that learning, at least when defined as the elimination of errors and integration of correct habits, proceeds equally effectively under all four conditions and that the number of trials is merely a function of the number of initial errors under each of the different conditions of learning. This sequence of effects with its bearing on the problem of relative retention has already been suggested.

From Table III it is also seen that the average length of trials is shorter for Blk than for any of the ideational forms. Since the average length of trials is the quotient, mean of time/mean of trials, the average length of the response can be

obtained by subtracting eleven seconds from the average length of the trials. This subtraction is necessary since eleven seconds represent the constant time of the stimulus presentation. Table III shows that the shortest responses were made under Blk, namely 11.7 seconds, as compared with 12.0 seconds for 1–2, 12.4 seconds for BQ, and 12.6 seconds for AB. All of the ideational materials resulted in lengthening the response time. Furthermore, whereas now the Blk requires the least time for response, the AB which likewise was somewhat unfavorable as an optimal learning condition does not show this shift towards a reduction in time of response.

In this connection, it was also shown that when subjects were required to perform as fast as possible the responses learned under Blk resulted in the most accurate as well as the fastest performance although differences were not statistically reliable. It is especially interesting that those ideational elements, 1–2 and AB, which might be supposed to contain the greater associative values resulted in an apparent disadvantage with respect to rate and time of performance. These observations in connection with the reports of a number of subjects that they "just went as fast as possible without thinking about letters or numbers" would lead one to speculate on just what the basic neural pattern might be in a highly efficient motor performance. The possible inference is that for most effective learning of a performance, the learning should be done in the manner of the final performance.

Finally, if the average number of seconds per error can be used as an indicator of the rate of elimination of errors, Blk has the advantage since Blk shows an average of 4.68 seconds per error while all ideational elements show a lower rate. Corresponding rates for 1–2, BQ, and AB are 5.10, 5.00, and 5.08 seconds per error. This would indicate that it required less time to eliminate errors under Blk than under any of the ideational forms. Under a separate section of this investigation not presented in this article, analyses were made of the curves which 'best fit' when the decrease in aggregate errors was plotted against the accumulative time. This likewise showed that the rate of elimination of errors is highest for Blk.

It would seem that there are at least two reasonable inferences: (1) That the apparent learning difficulty under Blk lies in the initial liability to incur more errors, possibly because the subjects have had little experience in learning motor habits without the aid of specific ideational aids. (2) That, once the process of learning has begun, the rate of elimination of errors is likely to be greater with non-associational materials; so that (3) if the learning process is practiced beyond the first criterion of learning, the motor habits are likely to be more effectively overlearned without than with the inclusion of the associational materials. It is admitted that the last inference is a projection beyond the limiting boundaries of the data presented. Yet in view of the apparent better retention of motor learning, such a suggestion does not appear to be out of order.

General Summary and Conclusions

The specific problem studied was the effect of introducing three types of ideational contexts in the learning of a patterned motor response. Data were collected by recording the trials, time, and errors during the learning process. Incidentally measurements of immediate recall, time of five speed trials and subjective reports on methods of learning were also collected on twenty-four of the forty-eight subjects used.

An analysis of the data suggests the following conclusions:

1. The introduction of ideational contexts in the learning of a patterned motor performance results in a distinct advantage at least during the initial stages of the learning process: (*a*) of the ideational contexts, the digits show the greatest advantage; (*b*) the unrelated letters show an advantage nearly equal to that of the digits; (*c*) the related letters show an advantage over the non-ideational material, but not as great as that of the digits or unrelated letters.

2. Reliable mean differences occur only between the minimum-ideational context and the most favorable of the ideational contexts, the digits and the unrelated letters. There are no significant differences shown between any of the ideational contexts, and the mean differences between the mini-

mum-ideational context and any one of the ideational forms are always greater than the intradifferences between ideational contexts.

3. When immediate recall is tested by the relearning method, it is shown that the highest saving scores occur in inverse order to that of learning.

4. Among individual subjects there are exceptions in the facility with which they learn under the different conditions, a small percentage of them learning as rapidly under the minimum-ideational contexts as others did with digits.

5. Differences in the relative advantages appearing in the initial stages of the learning process tend to diminish when learning is continued until the responses can be performed with speed and accuracy. It would seem that the performance of a patterned motor performance can be repeated most efficiently when learned without the use of ideational contexts, that is, in the manner in which it will eventually be performed. The average response for Blk throughout the entire learning process is also shorter than for any of the ideational materials.

6. Since the rate of elimination of errors seems to be approximately the same under all conditions of learning, differences in learning time and trials probably are due to the initial number of errors incurred. No explanation for the differences in the number of errors incurred in the beginning can be given at this time, but it is suggested that these may be due to the previous learning habits of the subjects.

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INTRA-SERIAL EFFECTS IN THE DISCRIMINATION OF COLOR MASS BY THE RANKING METHOD

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Ranking, possibly the simplest of all psychometric methods, has been used hitherto chiefly in studies of æsthetics, attitudes, and of hand-writing, drawing, and other material the stimulus value of which is determined on a subjective, rather than on an objective or physical basis, as in the case of weights or sound intensities. Where large numbers of stimuli are simultaneously presented to Ss to be examined individually and repeatedly, and where numerous Ss must be tested, ranking is probably the most satisfactory method. Reliability and precision, comparable with that produced by other methods (*e.g.*, the constant method), may later be obtained by scaling the rankings.

The discrimination of color mass has been described before (1). Essentially it consists in determining the predominating color of a group of colored stimuli (generally dots all of the same size). After preliminary practice the determination of the predominating color can be quickly and confidently established even by children.

The test material was printed in colors equated as closely as possible for brightness and saturation. As was pointed out in the previous paper perfect matches were not obtained; even if this had been done a number of factors, such as spacial induction, minuthesis, etc., would have disturbed the matching. The matches, however, were sufficiently good to give a graded series in each set of two hues, from a pronounced hue of one type, through equality, to a pronounced hue of the other type. As the stimuli may be graded to almost any extent of difficulty, material of this nature is excellent for psychophysical work. What is discriminated is not alone hue, nor brightness, nor saturation, but some combination of all three which appar-

ently is of a definite modality, and the perception of which is immediate, *i.e.*, without intervening judgment processes.

Procedure

Material.—The material consisted of a pack of 72 cards, on each of which were 36 dots, one quarter of an inch in diameter, spaced one eighth of an inch apart, and randomly distributed according to the following scheme. Starting with 23 dots of one color, *e.g.*, blue, and the remaining 13 dots of another color, *e.g.*, green, the cards went down in sequence diminishing one dot of one color and increasing one dot of the other color at a time, till there were 13 blue dots and 23 green dots on a card. Thus the entire pack was divided into six sets, of 12 cards each; and each set contained dots of only two colors. As four colors in all were used, blue (B), green (G), purple (P), and red (R), all possible combinations of these colors two at a time were used to make up the six sets. On the reverse side of each card was a code which gave the predominating color and the number of dots of the predominating color. When the cards had been ranked, they were turned over to expose the code, and the ranking of each card was marked down on a tabulating sheet.

Subjects.—The Ss were 32 adult women. One complete trial of the six different color sets was taken each day for 25 consecutive days. In a few cases a day or two was skipped, but the total number of trials was the same. A limit of two minutes was set for each combination; and the entire test had to be completed within fifteen minutes. The time limit was set primarily to avoid undue fatigue and to make sure that the dots were estimated as a mass, and were not counted. No difficulty, however, was experienced on that score as Ss soon found out that the first prompt judgment based on the total effect was much more effective than any other mode of estimating the color mass. All tests were taken in daylight, at approximately the same time of the day, and under the same general background conditions. Some minor variations occurred on this score but possibly they were trivial in effect compared with the daily fluctuations over 25 days in the physical and mental conditions of Ss themselves.

Instructions.—The instructions were as follows:

"This pack of 12 cards is to be arranged according to the amount of predominating color. Place the cards in two rows, the card with the most of one color (the specific color was named) to the left, graduating down to that with an equal number of dots of each color. In the second row place those cards with the greatest amount of —— color (here the second of the color combination was named) to the left, down to the card that contains an equal amount of the two colors."

"It is best to work quickly. Pick out each card and place it in its approximate position in the two rows. Check your judgment first from the maximum of one color to the maximum of the other color and back again."

The order of the sets for each test was as follows: Blue-purple, Red-green, Blue-red, Green-blue, Purple-red, and Green-purple. This order was not varied, and indicates not only the color combination but also which color was placed in the top row.

As will be pointed out later the instructions were all important in determining the effect of certain factors in the test. Thus the placing of the cards in two rows instead of one (originally done for convenience in spreading them out on a table) was of prime importance from the standpoint of the end effect. It will be noted also that the psychophysical orientation given to Ss was that of the absolute method, rather than the relative method of comparison; *i.e.*, Ss placed the cards in their approximate

positions on the basis of some absolute standard which they readily learned after the first trial or so.

Scoring.—Scoring was done in two ways. Errors were scored whenever a card was placed in the wrong position; one error being credited for each position that the card was misplaced from the correct one. Thus if a 19 Blue card was placed in 21 Blue position, two errors were counted. By summing up the errors made for each combination a score was obtained of the efficiency of every trial, and of the relative ability of each S. It also afforded an excellent means of telling when learning was complete, since a criterion of three successive errorless trials had been established for learning. From the scores made on successive trials the course of the learning could be plotted, and the difficulty of each color combination could be established.

The second scoring method consisted in tabulating for every S, the frequency distributions of each card in every color combination. That is, a tabulation was made of the way each card was distributed in the various positions. Here the stress was laid on the discrimination of the individual card, rather than on the discrimination of the color combination. Thus the psychophysical variables, such as the point of subjective equality (PSE), the time errors, the thresholds of discrimination, the precision and the skewness of the distributions could readily be ascertained.

Results

Learning.—Learning was completed within the given number of trials by 14 Ss, who averaged 16.8 trials to learn. This number did not vary greatly from one combination to the other. The average number of trials per quartile to complete learning was as follows: Q1, 13.0 trials; Q2, 22.0 trials; only a few Ss in Q3 learned one or more combinations; no S in Q4 completed the learning for any combination.

Perfect scores, *i.e.* no errors, were credited to Ss for all trials beyond the point of learning (first three perfect trials). This was done for both scoring methods. In some cases Ss did make errors after learning had been achieved. In 776 trials beyond the point of learning 238 errors were made out of a total of 16,946 errors in the complete investigation, about 1.4 percent. Thus it is seen that no great distortion in the final results was caused by omitting errors beyond the point of learning.

Intercorrelations.—A table of intercorrelations (Table 1) was compiled from the correlations of the error scores for each combination, and reliabilities were computed by the split-half method. The correlations are all unusually high; the average correlation being 0.9284 and the average reliability, 0.917. They are to be explained in part by the fact

that in every series there were 25 trials; yet the correlations for the first and the second trials run about 0.5; naturally when 25 trials are taken the correlations are stepped up considerably according to the Spearman-Brown prophecy formula. If we consider the six color combinations as forming one test, using

TABLE 1

INTERCORRELATIONS OF ERRORS MADE ON COLOR COMBINATIONS. (METHOD I)
Odd even reliabilities in *parentheses*. P.E. = 0.03–0.01.

Combination	PB	RG	BR	GB	PR	GP
PB	(.947)	.912	.882	.893	.915	.933
RG	.912	(.921)	.904	.927	.938	.923
BR	.882	.904	(.898)	.952	.959	.955
GB	.893	.927	.952	(.871)	.948	.933
PR	.915	.938	.959	.948	(.904)	.948
GP	.933	.923	.955	.933	.948	(.964)

the average intercorrelation 0.9284 in the Spearman-Brown prophecy formula we find the reliability of the entire test to be 0.987. Owing to the high reliability consistent results are obtained from which the time errors may be determined with some confidence.

Difficulty According to Color of the Cards.—As was previously explained an attempt was made to equate the colors for brightness and saturation. Even if the colors had been exactly equated, the varying amount of color and the randomness of the grouping of the dots, causing variations in the relative effects of the photochromatic interval, minuthesis, spacial induction, etc., would make for considerable variations in the apparent hue, saturation and brightness of the colors. In addition there were minor variations in intensity, due to printing difficulties, *i.e.* it was technically difficult to keep the ink constant in amount for each color on the cards. In general this has been fairly successfully done, as may be judged from Fig. 1 which gives the number of errors for each card, for all four colors. It will be remembered that since there were four colors, six color combinations in all, each color was presented three times in the course of the testing, and was predominant on half of each set (six times in twelve stimuli). From the figure it may be seen that Blue, Green and Purple are very

closely equal in difficulty, and Red is definitely easiest to judge. When the average number of errors made per half set of colors (*i.e.* on those halves in which the color predominates) are determined, they are respectively, Blue, 3.73,

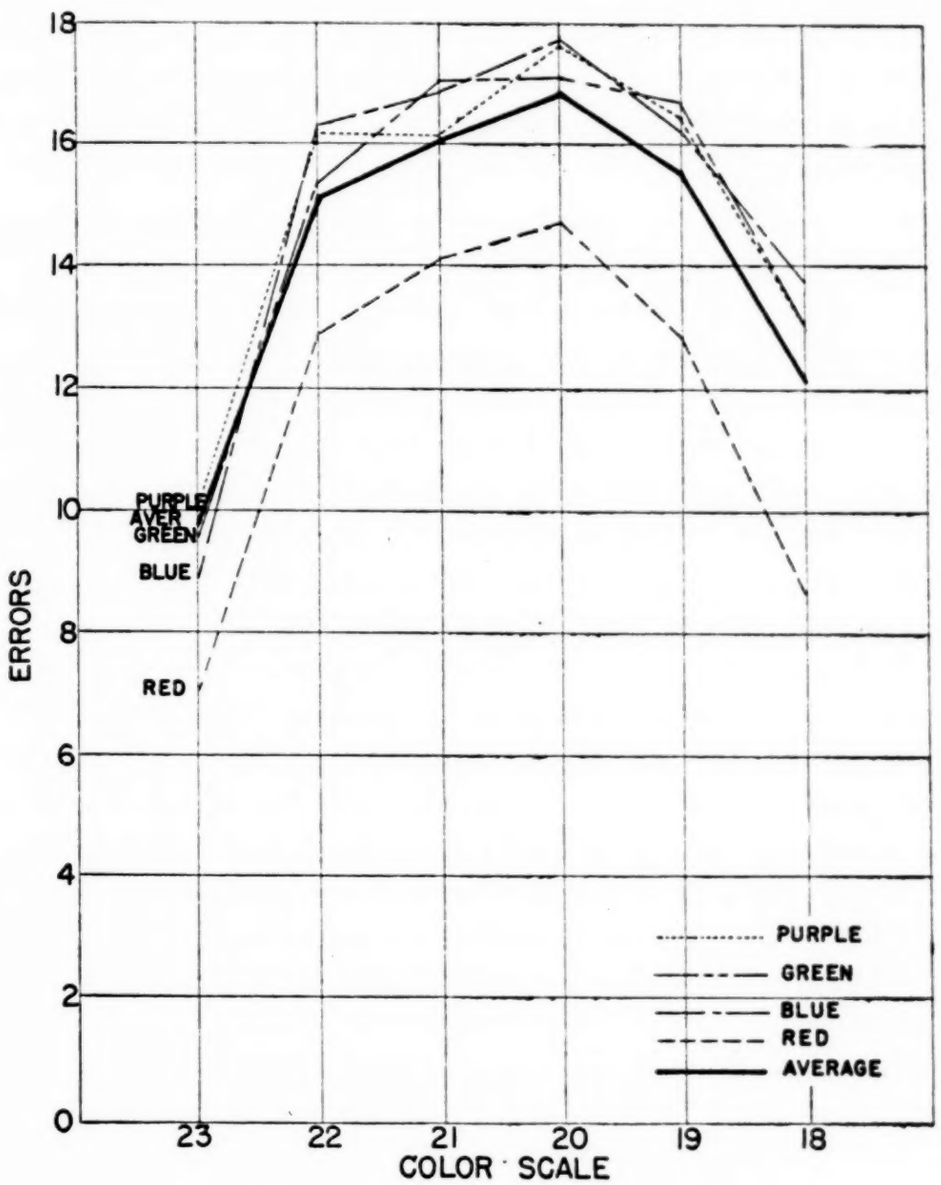

FIG. 1. Average number of errors made at each position for the different colors. Ss = 32; Trials = 25.

Purple, 3.72, Green, 3.69 and Red, 2.90. The relative ease of determining the Red color is not all due to the difference in brightness, etc., but possibly is chiefly due to the greater 'Eindringlichkeit' of Red. The color stands out very clearly;

in fact it seems to the subject who has been judging for some time to stand out from the plane of the card.

Difficulty According to Color Combination.—When the curves are plotted for errors made in each serial position (Cards, 23, 22, 21, etc.) for all the six color combinations, the form of the curve is the same, though all combinations are not equal in difficulty. The variation in difficulty is well shown by the average number of errors made per trial for each color combination. They are as follows:

BP	GB	GP	PR	RG	BR
8.42	8.13	7.33	6.48	5.96	5.82

This order of difficulty holds not only for all the Ss of the group when averaged, but also for each quartile with the exception that GB is slightly more difficult than BP for the first and second quartiles (the better half of the group); and RG and BR vary somewhat in ease of discrimination according to the quartile. The constancy of the order of difficulty of combinations is readily understood when we have in mind the high degree of reliability of the entire test.

Difficulty According to Serial Position.—There is a well defined variation in difficulty according to serial position. Fig. 2 shows the variation in error frequency according to serial position for all four quartiles and for the entire group. The similarity of curve forms is to be noted. The peaks of the curves tend to be somewhat flattened for Q1 and Q4; the best Ss discriminate quite well at all positions and the poorest Ss find it equally difficult to discriminate no matter what the serial position.

The forms of the curves are decidedly interesting, and they remain the same in general no matter how the data are fractionated. According to Weber's Law the discrimination should be progressively harder from the 23 cards to the 18 cards, and then should get easier again from the 18 card to the 23 card on the second half of the color combination. In other terms the curves should in general be concave downward. Instead there is a double concave curve, and the highest point of the curve, *i.e.* the maximum number of errors, is not made for the 18 cards, but for the 20 cards.

To understand this phenomenon, which appears so consistently in these data, it is well to understand that we are dealing with discrimination very close to the limen, at which point the judgment processes are very complicated, and are prone to vary subtly. The attitude, or set, is of great importance, as has been shown by many workers, notably

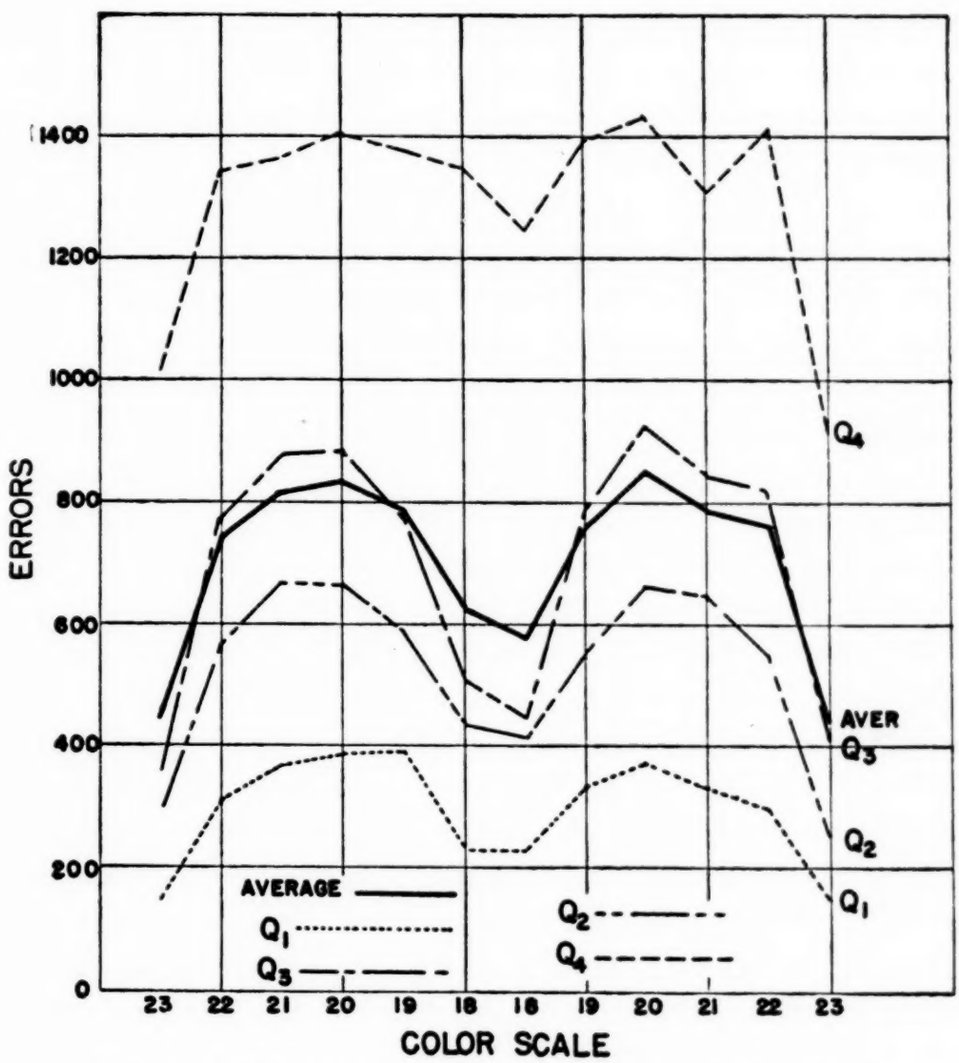

FIG. 2. Variation in error frequency according to serial position.

Woodrow (2). It will be remembered that the instructions require that the cards be set out in two rows, all those of one color in one row and those of another color in another row. There is therefore a two-fold task assigned; first, the discrimination of predominating color, and second, the discrimination of the degree of predominance of that color.

One might therefore expect a sharp break in the center of the series, where the difference in color comes. In other terms the series of 12 cards to be set out in serial order is not envisaged as one gestalt, but rather as two; it is not a series of Red-Green in one continuous unbroken order, but rather a graded series of Red and a graded series of Green. That this division line really occurs in the judgment process, possibly due to the instructions, is quite evident when a count is made of all cards misjudged for color; that is, when a card is placed by mistake on the wrong half of the series. A 23 card of course is six places away from the wrong side, but a 19 card need only be displaced two places to be assigned to the wrong color. Nevertheless there is a surprisingly small number of errors caused by placing a color on the wrong side. Out of 57,600 judgments, only 613 cards were assigned to the wrong side, about 1.07 percent; the percentages for the various colors being for Blue, 1.12 percent, for Purple, 1.26 percent, for Green, 1.11 percent and for Red, 0.78 percent. It is quite obvious therefore that a definite boundary is set by S at the midpoint of the series to divide one color from another: hence we get a double concave downward form to the curve.

The next point, and one more difficult to explain, is why the curves should be concave in form, and should not follow Weber's Law, which requires a progressive increase in errors from the 23 cards to the 18 cards. As was pointed out by Thurstone (3), Urban (4) and others, the very mechanical limitations placed on the distributions of the cards throughout the series would make for lesser errors at the 23 ends of the series. Thus when judging a 20 card the S could mistakenly throw the card either to the right or to the left; but the 23 cards can only be thrown in the correct positions, or with diminishing frequency, naturally, towards the 22, 21, 20, etc. positions. Urban claims that the distributions tend to normality in the center of the series, with a tendency for the end positions to be truncated normal distributions. That this is not quite true in this case is evident from Table 2, which gives the distribution of every card scored by Method II. Obviously the end distributions are somewhat more than trun-

cated normal distributions, they are markedly skewed. A glance at the table for cards 22 and 21 will show this most clearly. Reading along the horizontal lines for 22 we see that 706 cards were displaced one place to the right of the correct position (*i.e.* the open side) and only 435 to the left or closed side. In the horizontal row for card 21, the numbers of cards displaced one and two positions on the open or right side are 838 and 343, while toward the closed side the numbers of correspondingly misplaced cards are 714 and 210. Similar effects may be perceived at the other end of the scale. Mere

TABLE 2

COMPLETE DISTRIBUTION OF ALL COLORS. (METHOD II)

Positions	23	22	21	20	19	18	18	19	20	21	22	23
23	3903	449	195	146	76	19	9	1		1		1
22	435	2931	706	455	177	55	20	13	3	1	4	
21	210	714	2503	838	343	100	49	22	10	6	3	2
20	106	373	808	2532	614	198	95	40	11	13	7	3
19	67	191	368	506	2850	494	150	111	21	21	17	4
18	53	92	133	209	463	3021	544	143	55	38	36	13
18	9	25	46	59	118	561	2990	554	200	123	79	36
19	8	11	20	29	93	201	519	2880	472	310	194	63
20	3	6	12	13	27	83	220	601	2484	823	437	91
21	2	2	6	9	24	43	101	251	880	2558	714	210
22	2	4	3	3	9	20	72	138	500	690	2867	492
23	2	2		1	6	5	31	46	164	216	442	3885

mechanical limitation of the possible positions therefore does not explain all this effect even at the 23 ends of the scale. More particularly, in the center of the series, where the scale is open at both sides, and hence there are no strong mechanical limitations in the placing of the cards, the number of errors is likewise diminished, though not to the same extent. Yet according to Weber's Law the number of errors should increase at this end of the scale. Obviously factors other than mere mechanical limitation or statistical truncation are operating to cause the curve to take the form it does.

DISCUSSION

It is well to note that the effect here being studied, namely the diminution of errors in discrimination at the effective center of the series, is not to be explained on the basis of the law of central tendency of Hollingworth, which has been often

used to account for the occurrence of time errors. The effect of time error is an intricate one which has evoked many explanations. But the time error, particularly when estimated on the basis of the percent difference of lesser and greater judgments, by Pratt (**5**), Needham (**6**) and others, does not imply that fewer errors are made when the time error is small, but that the skewness of the incorrect judgments is positive or negative. The time error hypotheses merely attempt to explain how the incorrect judgments will be distributed, and do not refer to the frequency of the correct judgments, which we are discussing in this case. It is true that time errors occur in the data of this study, but they will be discussed in a further paper.

The explanation here advanced for the peculiar form of the curve of error distribution according to serial position, is based upon the process of judging. A judgment is never an isolated event, it is contingent upon some relative or absolute standard. Relative judgments are made when the comparison standard is simultaneously present with the material to be judged; absolute standards are framed out of a series of previous relative comparisons, and are retained with greater or lesser stability. No judgment can be made without some frame of reference, some 'point de repair,' some guiding post from which measurements either of equality or difference are made. Generally some fixed, definite standard is preferred to a standard that is diffuse and devoid of clarity of outline.

In the present instance the S selects the end of the series, *i.e.* the maximum amount of color as one frame of reference or guiding post; the other end of the series, the point devoid of predominance of color, *i.e.* the 18 card, is chosen as the other frame of reference, but naturally it is not so clear-cut as is the opposite frame of reference. All judgments are made on the basis of distance from these two guiding posts. Naturally the closer the card to be discriminated is to the frame of reference, the more accurate, surer and quicker will be the judgment. As one end of the series, the 23 card, is a more stable and definite standard than the other, judgments at that end of the series will have fewer errors than at the other

end of the series; but the judgments at both ends of the series will be better than those at the effective center, *i.e.* in the neighborhood of the 20 card position in the series, and this in spite of Weber's Law. Furthermore, owing to there being frames of reference at three points, the two 23 cards at the ends, and the 18 cards at the center, the form of the distribution curves of errors will be that of a double concave curve. Thus the attitude of acceptance of the two-fold task by the S is confirmed, that of discrimination of Red, say, from Green, and that of the discrimination of the amount of predominating color. And the frames of reference are from maximum amount of Red to equal Red and Green, and from this point to maximum amount of Green. A subsequent paper will attempt to extend this explanation to account for the sign and magnitude of the time errors.

Summary

Daily for 25 days thirty-two women ranked for color mass six different color combinations, twelve stimuli to a set. From scoring methods based upon errors and allocation to serial position the following conclusions were reached:

(1) Inter-test correlations and reliabilities are high.

(2) Color combinations differ in difficulty.

(3) The curve of serial difficulty of the stimuli is double concave, in opposition to Weber's Law.

(4) An explanation for this finding is advanced, based upon frames of reference at the limiting stimuli.

(Manuscript received March 19, 1940)

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THE EFFECT UPON REACTION TIME OF MUSCULAR TENSION INDUCED AT VARIOUS PREPARATORY INTERVALS

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Psychologists have long known that an important determinant of reaction time is the adequacy of the subject's preparatory set. Woodrow [1] showed that interval conditions between ready signal and stimulus presentation influenced reaction time, those of greater or less extent than a period of two seconds being reported unfavorable for most rapid response. There can be little doubt that Woodrow was working on the optimal placement of a preparatory set in relation to its associated overt performance and that, in terms of neural interrelations, his problem is similar to that of Bowditch and Warren [2] on the facilitation of the knee jerk by appropriate timing of some other motor process, such as clenching the hands. Preparatory sets for reaction time performance are primarily muscular,[3] and presumably their interaction with concurrent neural conditions initiated by external stimulus differs from the classical knee jerk experiments only in that the excitation in operation at the time of stimulation is originating primarily in the muscle group to be activated rather than spreading from muscular contractions originating elsewhere.

The purpose of this experiment was to test the hypothesis that the *timing* of the muscular set or preparation for voluntary reaction will influence the speed of that reaction after

[1] Woodrow, H., The measurement of attention, *Psychol. Monog.*, 1914, **17** (No. 5), 1–158.

[2] Bowditch, H. P. and Warren, J. W., The knee jerk and its physiological modifications, *J. Physiol.*, 1890, **11**, 25–64.

[3] Judd, C. H., McAllester, C. H., and Steele, W. M., Analysis of reaction movements, *Psychol. Monog.*, 1905, **7**, 141–184. Williams, R. D., Experimental analysis of forms of reaction movement, *Psychol. Monog.*, 1914, **17** (No. 75), 55–155.

the manner of Woodrow's interval analysis. The study is part of a program which seeks to understand the postural basis of set and which has been previously stated by the senior author as follows:

> "Whether tension (muscular set) will improve or hinder a given performance depends upon a number of factors including (1) the amount of tension developed, (2) the locus of the antecedent muscular contractions in reference to those involved in the test performance, and (3) the timing of these conditions in relation to release of the overt reaction by stimulus . . . these factors are mutually interdependent . . . but any one may be studied separately by holding the others constant while varying it systematically." [4]

In earlier studies the locus [5] and the amount [6] of experimentally induced muscular tension were found to be important determinants of the quantity and quality of overt response. In this experiment locus and amount of experimentally induced tension were held constant and a frontal attack upon the time factor was launched by initiating a tension 'set' in the reacting muscle group at various periods antecedent to the reaction signal. In so far as possible, we tried to duplicate Woodrow's work as a control, and substituted in our experimental series for his 'ready' signal an involuntary movement of the reacting limb at various intervals prior to presentation of the auditory stimulus to which *S* was instructed to react voluntarily.

The Experiments

Certain difficulties confront one in the substitution of experimentally induced muscular tension for verbal warnings in the reaction experiment. In the first place, the only feasible time-variation of antecedent tension is through some arrangement which will cause sudden limb displacement, and if *S* resists these displacements the degree of tension in the limb may bear no predictable relation to the experimental condition. Secondly, unless fairly constant tension levels are maintained in muscles other than that involved in the performance, changes in reaction time may be due to shifts in this general excitation background rather than to the experimentally induced tension. Finally, the effect upon reaction time caused by prior release of the reacting limb may be due to the sensory (kinæsthetic) warning involved and not to the antecedent motor condition, *per se*.

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[4] Freeman, G. L., The optimal locus of anticipatory tensions in muscular work, *J. exp. Psychol.*, 1937, **21**, 554–564.

[5] *Loc. Cit.*

[6] Freeman, G. L., The optimal muscular tensions for various performances, *Amer. J. Psychol.*, 1938, **51**, 146–150.

These difficulties were met in part by making the reaction movement one of the entire right arm, rather than the ordinary finger response,[7] and by placing this arm in an apparatus which developed tension producing movements at various intervals prior to the auditory stimulus. As indicated in Fig. 1, the subject was seated in a comfortable chair with his arm attached to an arm board, blindfolded, and relaxed. The arm board was swung back through an arc of about twenty degrees, held in this position for fifteen seconds, then (as an electromagnetic circuit was broken) released and carried forward through an arc of about forty-five degrees by a strong spring and allowed to come to rest. At two to eight seconds thereafter, a buzzer was sounded to which S reacted by a slight forward movement of the arm board. Reaction time was, therefore, recorded for stimuli following at various intervals the introduction of the tension producing movement. Subjects spent several hours in training to keep generally relaxed during the arm swing. Furthermore, when the board stopped they made no effort to maintain any particular position but let it come to rest as it would had the arm not been attached.[8]

Two series of observations were made. In series I, a heavy tension load was induced at various intervals before voluntary reaction to auditory stimulation. Three subjects performed under the four following conditions: (1) tension induced in 40 consecutive trials each at 2, 4, 8, and 10 second intervals before stimulation; (2) control for condition one, with only warning interval varied serially (no tension induced); (3) tension induced at 2, 4, 8, and 10 second intervals before stimulation in irregular order (40 trials each); (4) control for series 3, with only warning interval varied at irregular intervals (no tension induced). In series II a lighter tension load was induced at varying time intervals and with somewhat better general controls than series I. Six subjects performed here under the following two conditions: (1) control, with tension and no tension [9] presented in alternate groups of 25 trials each for intervals of 2 and 4 seconds; and (2) with tension induced in 25 consecutive trials each at 1, 2, 4, and 8 second intervals before stimulation. In series II more time was spent on training *S* for general relaxation and check on such relaxation was obtained from records of palmar skin resistance.[10]

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[7] HATHAWAY (*J. exp. Psychol.*, 1935, 11, 285–298) reports that the reaction times are longer for this movement than for finger reactions, but experimental effects should be in the same direction.

[8] Because the subject's arm was not held in any particular position after the tension producing movement the reaction key was an ordinary knife switch attached to the arm board by an adjustable cord so that as the board came to rest the reaction movement pulled the taut cord and thus opened the circuit and stopped the chronoscope. Variation in body build made it necessary to adjust the length of the arm board for different subjects. The board was padded and leather straps were used at the elbow and wrist to maintain the arm in the same position on the board throughout the series of reaction trials.

[9] To test the relative importance of the sensory warning cue (derived from kinæsthetic impressions of antecedent movement) and the muscular condition itself the no-tension condition moved the arm very slightly, at various intervals prior to stimulation, and let *S* use these subjective impressions of movement as a 'ready' signal.

[10] Palmar skin resistance readings, taken in the control condition of Series II were averaged to obtain a basal level for each subject. In the experimental series *S* was brought down as close to this previously established level as possible before starting a given set of trials.

In both series I and series II subjects were given 50 to 100 preliminary practice trials. Subjects were not kept in the apparatus for longer than an hour each day, and since our experimental conditions often required longer periods for completion, care was taken to counterbalance day-to-day practice effects in each subject and to vary the order of presenting these conditions from subject to subject. The instructions were:

> "Your arm will be placed in the apparatus and you will be blindfolded. Relax yourself completely. When it seems that you are thoroughly relaxed, we will begin the experiment. Your arm will be swung through a small arc. Do not resist this involuntary movement and when stopped let the arm remain in that position. As soon as you hear the click react by making a short forward movement of the arm. Remember to keep relaxed all of the time and to disregard any sounds or noises other than that of the click to which you are to react. Remember that the arm-swing is an incidental feature of the experiment and do not pay any particular attention to it. Concentrate your attention on listening for the sound to which you are to react."

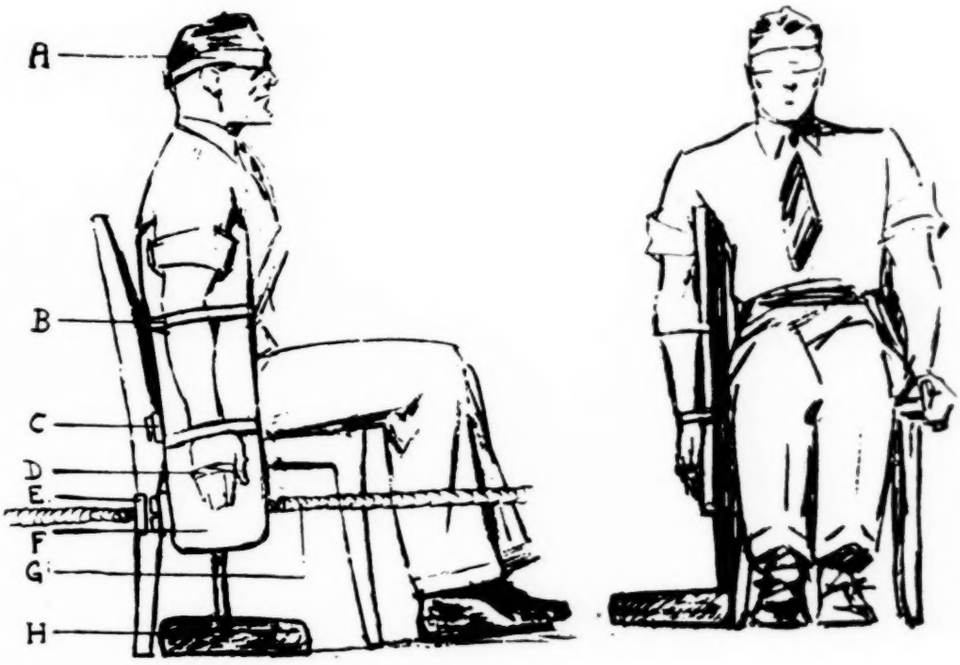

FIG. 1. Showing apparatus for inducing tension; *A*, subject seated and blindfolded, *B*, arm held on board (*F*) by strap, C, reaction switch, *D*, electrodes for *GSR*, *G*, spring for sudden limb displacement, *H*, base and support for arm board, *E*, magnetic switch.

RESULTS

Due to the limited number of cases included in our study, individual analysis of the data will be made. In Fig. 2 we present the mean reaction time of each subject at intervals of 2, 4, 8, and 10 seconds after introduction of various tension or non-tension conditions.

The above results suggest that when warning period alone is varied in reaction time experiments, the optimal interval varies considerably from individual to individual. Thus, subject E gave optimal reaction times following the 8-second interval while subject A's optimal intervals are 2 or 8 seconds,

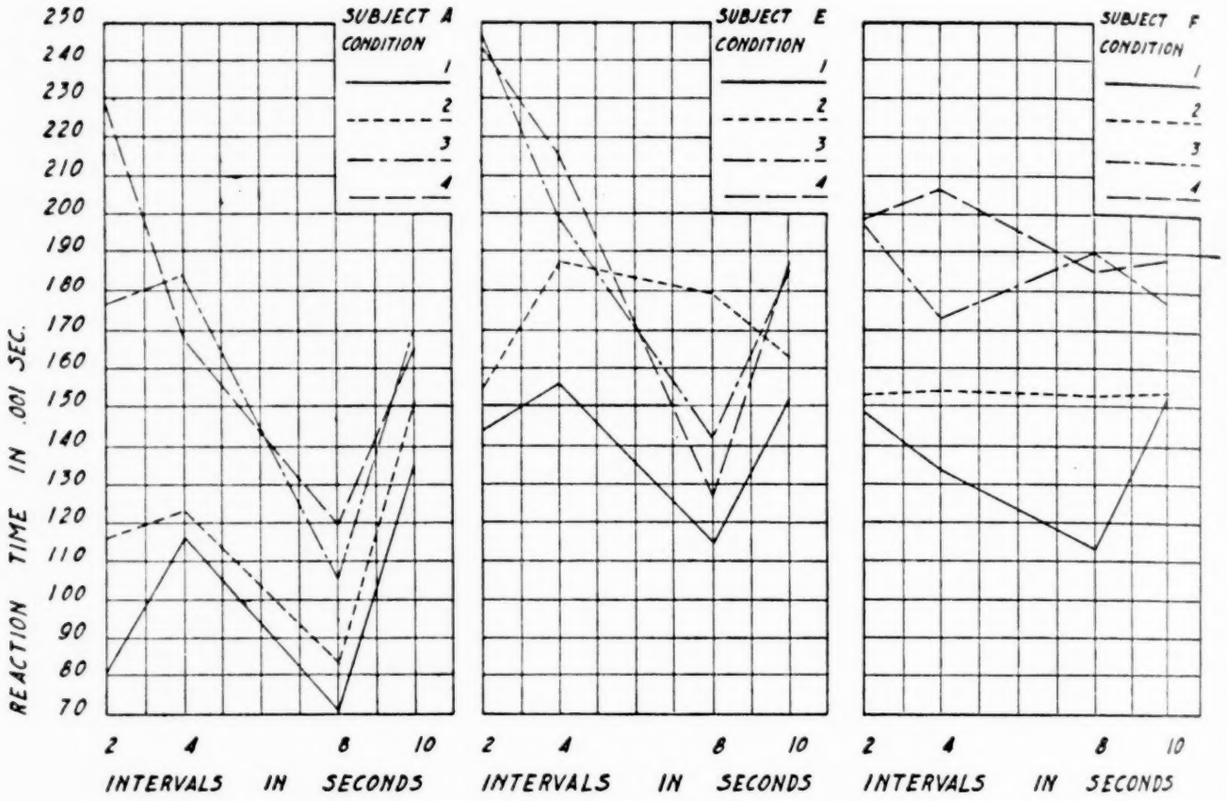

FIG. 2. Showing the mean reaction time when *heavy tension* was induced (Series I) at various intervals prior to stimulation; (condition 1, serial presentation of tension intervals; condition 3; irregular presentation of tension intervals; condition 2, serial presentation of warning intervals alone; condition 4, irregular presentation of warning intervals alone).

and subject F shows no well-defined optimal condition, so far as warning interval alone is concerned.[11] There is also considerable variation within the same individual, as indicated by standard errors. Thus, for condition 2 (serial presentation of

[11] It is unfortunate that the pioneer study by Woodrow cannot be checked for reliability of means. The average curve, published in so many textbooks, was obtained on only three individuals (25 reaction trials on each interval). The difference between, for example, the 2 and 8 second interval in the average curve is .032 seconds. If the standard errors of individual subject's score on each interval (not given) were of the same order as ours, the *t* value (using Fisher's test of significance) would lie between the 10 percent and 5 percent level of significance and would ordinarily be rejected.

intervals alone) average standard errors were: Subject A—7.9, Subject E—5.5, and Subject F—8.5; and for condition 4 (irregular presentation of intervals alone) the average standard errors were: Subject A—15.9, Subject E—13.9 and Subject F—14.6. Such variations in reaction time might be expected due to fluctuating set conditions with only warning interval as a source of control.

When a systematic attempt is made to control the locus and amount of anticipatory 'set' or tension (as we did in conditions 1 and 3), all subjects tend to show an optimal preparatory interval at 8 seconds. Furthermore, the individual reaction time means show less variation under tension than under no tension (control) conditions. Thus for condition 1, the average standard errors were: Subject A—6.6, Subject E—5.3, Subject F—5.5; and for Condition 3, the errors were Subject A—13.5, Subject E—12.6, and Subject F—18.3. Furthermore, when localized and quantified anticipatory 'set' tension is developed prior to stimulation, reaction time is shortened (over the control) regardless of interval.

We have not attempted to discuss the significance of the reaction time differences under the various tension intervals mentioned above, because a more complete series of data was obtained in the second experiment. Since less tension was experimentally induced in this Series than in Series I we also get some insight into the effect of *amount* of tension upon the optimal interval.[12]

The results of introducing muscular tension at various intervals prior to reaction are shown in Fig. 3. We see at once that, as a result of the lighter degree of induced tension, the fastest reaction times tend to follow the 4-second interval rather than the 8 second interval of Series I.

The individual means on all intervals are more reliable than those of series I. While the average standard error is greater for the six subjects in series II (M—8.4, Q—9.4, R—9.9, Sc—10.6, Sp—12.5, W—10.9) than for the three subjects in series I, the fact that the difference between means in

[12] It was unfortunate that this second series had to be run a year after the first and that the original three subjects were not available for further study.

series II is proportionally greater does not make the standard scores for series II greater than for series I.

We have not graphed the means obtained for tension *vs.* non-tension at 2 and 4 second intervals (condition 1); but the differences between these means are the most reliable of our

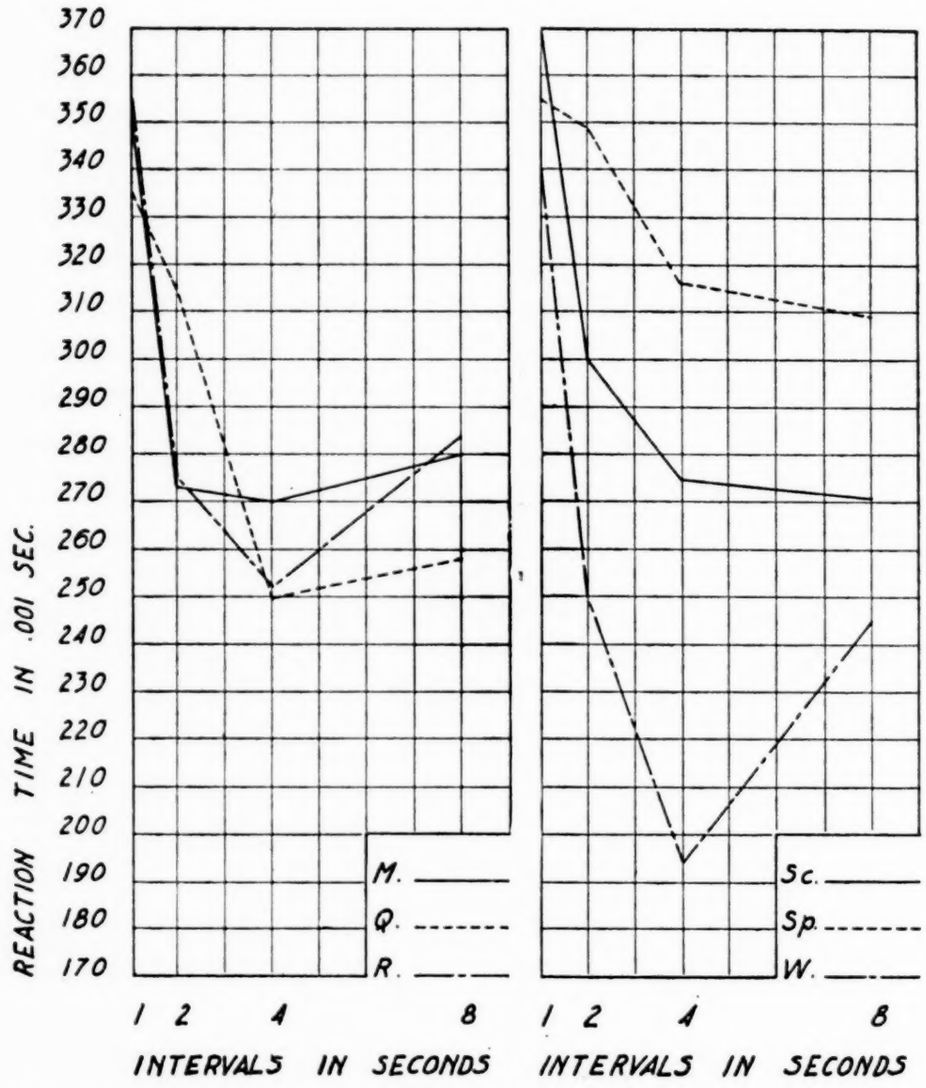

FIG. 3. Showing the mean reaction time for six subjects when *light tension* was induced (series II) at various intervals prior to stimulation (Condition 2, serial presentation with tension).

entire experiment. Thus, for a 4-second interval tension markedly facilitated reaction time in all subjects; and while for the 2-second interval, no tension was found to facilitate reaction more than tension in four out of five cases, the differences appear significant in only two cases.

In Table 1, we have computed for each subject in Series II the difference of reaction time means for all tension-accompanied intervals and indicated the significance of these differences. In this table significance is estimated using the 't' test after the manner of Fisher [13] rather than the more common critical ratio. This is to be preferred, especially in work with small samples, because it provides a test which not only takes into account the size of the sample but also makes no assumptions of normal distribution. In this table, the test of significance is set at the 5 percent level where *t* is equal to or

TABLE 1

VALUES OF '*t*'‡ OBTAINED FROM COMPARISONS OF REACTION TIME MEANS OF SERIES II

	THE MEANS COMPARED *							
	In Tension Interval Condition						In Control-Condition	
Subject	1 sec vs. *2 sec*	1 sec vs. *4 sec*	1 sec vs. *8 sec*	2 sec vs. *4 sec*	2 sec vs. *8 sec*	*4 sec* vs. 8 sec	2 sec (tension) vs. *2 sec (no tension)*	*4 sec (tension)* vs. 4 sec (no tension)
M	4.77	4.84	4.35	.36	.84*	1.14	2.13*	—
Q	1.90	6.02	6.65	4.28	4.47	.58	2.70	11.1
R	4.32	6.67	4.65	1.34	.55*	2.66	1.30	3.37
Sc	3.73	4.71	5.54	1.64	2.39	.26*	.13	2.73
Sp	.32	2.11	2.86	1.76	2.41	.35*	2.69	—
W	4.30	6.99	4.09	5.62	.35	3.59	—	4.20

‡ Where *t* is equal to the deviation of mean difference from a hypothetical difference of zero, divided by the standard error (as estimated from the degrees of freedom).

* Lesser mean as italicized unless indicated by an asterisk (*).

greater than 2.064. Checking through the table one sees that for 29 of the 45 comparisons which have been made the *t* value exceeds the level of significance, and hence we can conclude that the differences represent true ones (*i.e.* are due to our experimental conditions rather than to chance fluctuations).

As a final check on the validity of our general method of attack and of the reliability of the data obtained, we should mention that in Series II subjects tended to show the same reaction time means following 2 and 4 second tension intervals on different days and regardless of differences in general condi-

[13] FISHER, R. A., *Statistical Methods for Research Workers*, 7th edition, Edinburgh, Oliver & Boyd, 1938.

tion. This is clearly indicated in the comparison below:

Subjects	M	Q	R	Sc	Sp	W
Condition 1, 2 seconds after tension.....	273σ	315σ	275σ	300σ	350σ	250σ
Condition 2, 2 seconds after tension.....	261	325	282	293	291	
Condition 1, 4 seconds after tension.....	270	250	256	275	316	194
Condition 2, 4 seconds after tension.....		252	266	180		194

It will be recalled that in series II, palmar skin resistance was taken as a measure of general bodily excitation. It was hypothecated that a low degree of general activity would accompany a successful no-tension condition (that is, if uncontrolled auxiliary tension did not develop markedly) and that little or no difference in degree of general excitation would be found due to the way in which parts of the tension series were arranged. This hypothesis was confirmed by the resistance measures, and it was also shown that subjects were fairly successful in attaining the same initial resting level for all parts of the series; *i.e.*, each *S* tended to have the same general excitation background before the various tension intervals were experimentally induced. Further analysis of the relation between initial resistance level and performance would not be especially relevant to the problem in hand.

Discussion

The present investigation indicates that time relations between the involuntary (tension producing) movement in an arm muscle and the subsequent voluntary movement of that arm have important consequences as to its speed of reaction. Specifically, an optimal reaction interval exists for each subject, and this differs with the amount of antecedent tension induced. The fact that the same subjects gave most rapid reaction times when the only experimental variable was a certain length of warning interval, suggests that here also an optimal tension condition was operating. It is regretted that this study does not provide evidence (as from muscle action potentials) of the amount of tentative or covert muscular contraction developed in response to the heavy and light ten-

sion loads or to the ready signal alone, and operative at the moment of stimulus presentation; but the fact that other work has shown such contractions to be present when an individual gets set to react prompts the deduction that measures of muscular tension taken during any of our conditions would have shown that the optimal reaction interval shifts according to the degree of antecedent motor activity developed in the muscle. In other words, it takes a muscle a certain time to reach a condition favoring most rapid response to external stimulation and if application of the stimulus-to-be-reacted-to is delayed beyond the point where the muscular 'set' condition has passed its 'peak,' overt response will suffer; presumptively, the muscular condition operative at the moment of stimulation will be related to the amount and locus of the tensions previously induced and different optimal intervals will be found between the initiation of the 'set' condition and discharge of the overt reaction.

In previous reports, the senior author [14] has applied various terms and concepts to the problem of set. The present study suggests a further clarification. Specifically, the terms 'tonic' and 'phasic,' which have been used frequently to distinguish a neuromuscular 'set' from the overt 'response' it sustains, are not mutually exclusive. In motor reactions, certainly, the tonic set or focused pattern of muscular tension is to most intents the phasic response-to-be. But neuromuscular sets are not limited exclusively to or identical with the muscular conditions primarily involved in the overt response. Since the time of Sherrington, we have known that while the overt (phasic) aspect of response may be confined to a given muscle, covert activity present in associated muscles forms an essential part of the total reaction. The tonic set in reaction time experiments probably tends toward a somewhat more diffuse arousal of the musculature than does the phasic response; and while antecedent 'sets' are usually focalized in a soon-to-be-overtly reacting muscle, their effect on the condition of that muscle are not necessarily limited to the amount of prior

[13] FREEMAN, F. L., The problem of set, *Amer. J. Psychol.*, 1939, **52**, 16–30; The spread of neuromuscular activity during mental work, *J. Gen. Psychol.*, 1931, **5**, 479–494.

tension originally induced at that locus, as by a 'ready' signal. It is generally agreed that a muscular condition in any part of the body may influence the excitation level of any other muscle by way of proprioceptive pathways. Thus an individual might get 'set' for finger reaction by a tonic contraction of the leg muscles—these effects spreading to the finger muscles and so preparing them for rapid response. This is an uneconomical way of developing an appropriate antecedent set condition, but there can be little doubt that many persons, lacking better training, engage in this costly manner of preparing for work.

Finally, we may not assume that greater antecedent excitation or tension developed in a muscle group necessarily leads to a more rapid overt response. It is already known that too much tension will immobilize a muscle just as too much stretch of a rubber band will make it unresponsive to stimulation. The so-called *optimal interval* for reaction time will be a function of the amount of 'set'; for, as shown in our experiments with the heavy tension load, considerably more time must elapse before optimal reactions are obtained than when a lighter tension load precedes stimulus presentation. This is either because the muscle is at first so overloaded in the heavy tension condition that external stimulation has to wait until a later interval to catch the muscle at a decreased and more appropriate level for reaction, or it may be that the heavy tension load takes a longer time to develop the initially high optimal muscular readiness to respond.

It has already been demonstrated with simultaneously induced tensions that there is an optimal tension loading for the most efficient performance of a task. We should expect similar relations to hold for successive conditions, as when fastest reaction time results from antecedent induction of tensions. We should also expect that if we induced an arbitrary amount of tension and then varied the interval between such a condition and stimulus presentation the reaction time would at first be relatively long, reach a point at which the subject was working at his fastest, and then drop off again. We are led to expect this to happen because the muscular

residuals of the involuntary tension producing movement will probably take a brief period to rise to the point at which they can best support the phasic reaction, and may then begin to decline.

The major issue in current theorizing about set phenomena is whether or not the covert or incipient muscle activities found to precede reaction differ only in degree from the overt pattern of response. The simplest assumption for our present experiment is that the tension condition of the muscle *per se* rendered it more responsive to external stimulation and that overt reaction was merely a matter of simple accretion in excitation due to such stimulation. This theory may be fairly adequate to simple reaction performances, when a specific stimulus in anticipated by and flows into a specifically prepared channel of response. But when a greater latitude of stimulus possibilities is anticipated, then the interaction of excitation of external origin and that associated with the muscular set requires more complicated assumptions. Here the tonic set cannot be identical with the phasic response, for the overt responses which appear differ in character from the preparatory set. To explain how a given tonic set may sustain a variety of phasic responses we must appeal to the retroflexive mechanisms which places excitation from the 'set' in the brain field along with the excitation of external origin and make the overt response the *product* of their dynamic interaction. One may argue that such assumptions become necessary even in simple reaction time performances, for the set of the primary reacting muscle would have difficulty in directing the externally aroused excitation to itself unless it acted retroflexly to lower the response threshold of the cortical motorneurones concerned with initiating the voluntary efferent discharge.

Summary

This study was designed to test the hypothesis that the optimal warning interval found in reaction time experiments is a function of the response curve of a preparatory muscular set. A frontal attack was developed by inducing tension of

controlled intensity and locus at various intervals prior to stimulus presentation. Two series of experimental observations were made, one with light and one with heavy tension loads induced in the reacting limb, and control observations were taken with only warning interval varied. Tension induced at certain intervals prior to response lowered reaction time significantly. The heavy load condition showed a longer optimal preparatory interval than did the light load condition. The implication of these results for the problem of set-response dynamics is discussed.

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THE RELATION OF SIZE OF STIMULUS AND INTENSITY IN THE HUMAN EYE: III. THE INFLUENCE OF AREA ON FOVEAL INTENSITY DISCRIMINATION [1]

BY C. H. GRAHAM AND N. R. BARTLETT

From the Psychological Laboratory of Brown University

Two papers (**3**, **2**) from this laboratory have been concerned with the relation between the size of the retinal image and the intensity of light required for threshold in the human eye. Experimental data have been obtained with white (**3**) and red and violet light (**2**) for the periphery and fovea. In addition, the reports consider a theory which gives a simple and fairly exact account of the area-intensity function. The present experiment extends the general notions contained in these papers to the data of foveal intensity discrimination.

A number of well conducted experiments have been concerned recently with the influence of area on intensity discrimination [*e.g.*, Steinhardt (**8**), Crozier and Holway (**1**), Holway and Hurvich (**7**), earlier references cited in (**7**)]. Despite this fact, it seemed worth while to make further measurements in order to meet two conditions necessary for an experiment suitable to our particular purposes. The first of these conditions requires that we obtain a sufficiently numerous sample of areas below a limiting diameter of one degree. In this way, and with good fixation, it is possible to arrive at a clear picture of the influence of area on cone functions. The second condition requires that the exposure time of ΔI be restricted to a value below the critical duration for the reciprocity effect of time and intensity (Graham and Kemp, **5**). In this way we eliminate the possibility of anomalous effects due to a variable critical duration. In the present experiment the two requirements have been met by (1) the provision of six circular areas varying in angular diameter from 4 min to

[1] Supported by grants from the Carnegie Corporation and the John and Mary R. Markle Foundation.

56 min and (2) the restriction of exposure time to a constant duration of 0.03 second, a value which is probably below the critical duration for any of the areas and adapting intensities used in our experiment.

Method

The apparatus is designed to increase momentarily the illumination on an observation screen with brief flashes of variable intensity (ΔI) during the time that the screen offers a steady level of adapting intensity (I). In any one experimental session the value of the momentary increment in intensity which can just be discriminated by the subject is determined at levels of adapting intensity covering a range of nearly 5 logarithmic units. The area of the stimulus surface remains constant during a given experimental session, but is varied in different sessions over a range extending from an angular diameter of 4 min at one extreme to 56 min at the other.

The light-source is a 200-watt projection lamp operated on 110 volts d.c. The lamp is surrounded by a metal hood from which the light rays emanate through two small apertures at the level of the filament. One aperture faces a system of three lenses leading to the observation screen. The beam passing through this system affords the constant adapting illumination, I. The total distance from the aperture to the screen for this beam (the I-beam) is 70 centimeters. Wratten neutral-tint filters introduced at a point between the first and second lenses may be used to reduce the maximum adapting intensity in logarithmic steps.

The other aperture, in the side of the hood, allows light to pass from the filament through a condensing lens to a mirror. From this point the light is reflected through three lenses to illuminate the same observation screen as is illuminated by the I-beam. This system provides the ΔI-beam. After reflection from the mirror, the beam is brought to a focus by the second condensing lens in the plane of a disc which is part of a synchronous motor shutter similar to the one described by Graham and Granit (4). A sector cut in the periphery of this disc serves as a shutter to admit the beam for 30 milliseconds to the part of the optical system lying beyond. The third lens of the system is a short distance beyond the shutter and beyond the lens is a Wratten neutral tint wedge and its balancer. After passing through the wedge the light rays traverse a holder for Wratten neutral tint filters and another condensing lens. From this point they diverge slightly to illuminate the opal glass screen common to both beams.

It may be seen from the above description that our apparatus provides two beams from the same filament, both of which illuminate a common observation surface. This surface is of ground glass and acts as the diffusing source for the illumination of the eye. Measurement with a Macbeth illuminometer showed the intensity resulting from each beam to be evenly distributed over the surface. With no neutral filters in the system the brightness due to the I-beam was 555 millilamberts; to the ΔI-beam, 375 millilamberts.

In order to vary the area of the ground glass source we cut circular apertures in strips of thin brass. The strips were made to fit snugly against the observer's side of the ground glass. The apertures are circular with radii ranging from 0.87 to 12.2 millimeters. At the artificial pupil (3 mm diameter), which is 142 centimeters from the stimulus patch, the radii of the apertures subtend angles of 2.0, 3.3, 6.0, 10.0, 16.3 and 28.0 minutes.

Fixation is achieved by means of a device similar to one described by Graham, Brown & Mote (3). A box, 8 cm deep is fastened in such a position that the ground-glass screen and an adjacent dark expanse appear through a circular aperture, 3.5 cm in diameter, cut in the center of the box's rear surface. The inside of the box is painted flat white; the outside has a coating of lamp-black. By this arrangement the subject is presented with a visual configuration in which the stimulus area seems to be circumscribed by a black area 35 millimeters in diameter, which in turn is surrounded by a white area. Within the box itself, two small bulbs, operated at 3.0 volts from a storage cell, illuminate the white area with a brightness of about 0.15 millilambert, a value approximately 3.6 logarithmic units below the maximum brightness of the I-beam. An aperture 127 millimeters in diameter is cut in the side of the box farthest from the screen in such a position that its center coincides with the axis from the artificial pupil to the center of the illuminated stimulus patch. Under these conditions one sees, through the pupil, a dimly-lighted circular area of five degrees solid visual angle. In the center of this region is a black area of 80 minutes solid angle. The stimulus patch, illuminated by an appropriate adapting intensity, appears in the center of the black area.

A single determination under the conditions described above consisted in having the subject adapt to a particular intensity, I, on the stimulus patch. After complete adaptation a flash of the ΔI beam was presented. If the flash was not seen, the experimenter moved the wedge one centimeter toward its less dense end and then admitted another flash. This procedure was continued at intervals of about thirty seconds until the observer reported that he saw the flash. The average of four such determinations was taken as the 'ascending' discrimination threshold. At another session the threshold might be obtained in the 'descending' order, *i.e.*, by successively diminishing the intensity of a noticeable flash until it could no longer be reported. Two 'ascending' and two 'descending' thresholds were found for each of the six areas and for adapting intensities ranging from the maximum to a value near threshold. Four such series of threshold determinations were made for each area. Two of these series started with a maximum intensity for I and passed to threshold; the other two began at threshold and increased in intensity.

The procedure with each subject included a preliminary dark-adaptation of fifteen minutes. At the end of this time the lamps in the box were lighted and the subject placed his left eye against the artificial pupil through which he regarded the center of the dark area in the fixation box. He was allowed two minutes to adapt to the prevailing brightness on the ground glass screen at the center of the dark area. The discrimination threshold was determined in the manner described above and shortly afterwards a new adapting intensity was presented. Again the two-minute adaptation interval was given and the measurement of the threshold carried out as before. This procedure was repeated on a given day for a constant area and for all levels of adapting intensity.

Results

In Table 1 are presented the log $\Delta I/I$ values obtained at various levels of adapting intensity, log I, and for the various areas used. The data are for two subjects, Be and Ba. Figure 1 gives a graph of the data for subject Ba, and since

this figure represents in general outline the data of Be, it may conveniently be used for a discussion of the results. The number beside each curve represents the radial value in minutes of the particular area used in obtaining the data of that curve.

TABLE 1

LOG $\Delta I/I$ VALUES (SUBJECTS Be AND Ba) FOR VARIOUS VALUES OF LOG I AND FOR THE DIFFERENT RADII OF STIMULUS USED IN THE EXPERIMENT

Intensity values are in terms of photons. "White" light used for all determinations.

Log I	Subject	Log $\Delta I/I$					
		28 min	16.3 min	10 min	6.0 min	3.3 min	2.0 min
4.11	Be	−1.33	−1.16	−1.02	−0.57	−0.45	−0.53
	Ba	−1.51	−1.31	−1.08	−0.66	−0.49	−0.52
3.51	Be	−1.41	−1.05	−0.97	−0.47	−0.18	−0.31
	Ba	−1.51	−1.30	−1.13	−0.61	−0.33	−0.47
3.11	Be	−1.38	−1.07	−0.91	−0.65	−0.08	−0.16
	Ba	−1.51	−1.36	−1.08	−0.68	−0.35	−0.47
2.51	Be	−1.34	−1.14	−0.99	−0.43	−0.07	−0.11
	Ba	−1.54	−1.35	−1.08	−0.65	−0.33	−0.32
2.11	Be	−1.25	−1.18	−0.99	−0.42	−0.11	−0.05
	Ba	−1.45	−1.33	−1.03	−0.64	−0.37	−0.30
1.51	Be	−1.07	−1.00	−0.88	−0.39	−0.07	−0.03
	Ba	−1.27	−1.20	−0.99	−0.51	−0.29	−0.18
1.11	Be	−0.90	−0.92	−0.74	−0.43	−0.07	−0.03
	Ba	−1.12	−1.09	−0.80	−0.51	−0.27	−0.07
0.51	Be	−0.56	−0.59	−0.46	−0.20	+0.10	+0.17
	Ba	−0.78	−0.65	−0.49	−0.19	+0.05	+0.30
0.11	Be	−0.31	−0.28	−0.24	+0.05		
	Ba	−0.48	−0.26	−0.16	+0.06		
−0.49	Be	+0.20	+0.23				
	Ba	+0.12	+0.29				

It will be seen in the figure that, for any specific area, the log $\Delta I/I$ values are high at a low adapting intensity, I, and decrease in magnitude along a smooth curve which eventually approaches a final steady level at high intensities. This is the characteristic relation of $\Delta I/I$ and I and from this point of view our data are in line with the results of other investigators.

The influence of area is clearly shown in the graph. The effect of an increase in area is to displace the log $\Delta I/I$ values downwards along the ordinate at comparable values of log I. Thus, the curve for a radius of 28 min is lowest along the ordinate, and the curve for 2 min is, for the most part, highest.

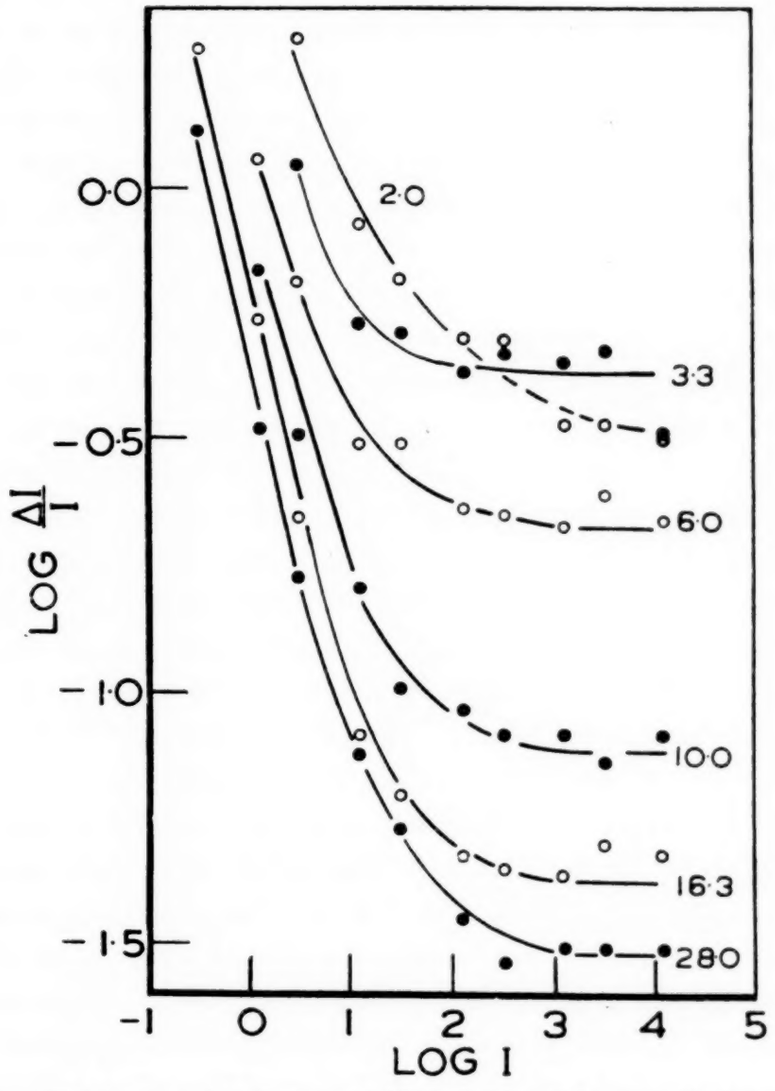

FIG. 1. The manner of variation of $\Delta I/I$ with I for different radii of stimulus area. The number beside each curve indicates the radial value of the stimulus in minutes. Data are for subject Ba.

Intermediate values of radius have curves which occupy intermediate positions between these extremes in an orderly arrangement. This regular displacement of curves with an increase in area (exclusive of the anomalous 2 min curve) is indicative of some sort of a reciprocal relation between $\Delta I/I$

and area for constant values of I; *i.e.*, the smaller the area, the higher the value of $\Delta I/I$; and conversely, the larger the area, the smaller the value of $\Delta I/I$.

The curves for the different areas are displaced along the ordinate, but they are probably not parallel to each other, even if the curve for 2 min be disregarded. It is likely that there is, in addition to the displacement along the ordinate, a slight displacement along the abscissa. However, this effect is slight, its magnitude approaches the limits of reproducibility, and for approximate purposes it may be disregarded.

The position of the 2 min curve is anomalous. It starts out above the 3.3 min curve at low values of I, but crosses the latter at higher intensities. In this regard it seems to provide an exception in the uniformity of our findings. For this reason it is important to realize that the points at the highest intensities on this curve (and indeed on the 3.3 curve) may to some extent be determined by interference phenomena which play a rôle with small apertures. The phenomena may be classed as (1) diffraction effects external to the eye, and (2) diffraction within the eye: random scattering by substances within the transparent media. With increase in the visual angle both effects diminish in importance, and for our larger areas may be disregarded. The effects due to (1) were minimized so far as possible in this experiment by using a large distance between the observer and the stimulus plane, but even so, interference is not negligible for high intensities when the smallest apertures are employed. In addition to the rings due to Fresnel diffraction the subjects reported the presence of streaks radiating from the center. These may be attributable to scattering by substances within the eye. It is clear in the light of these considerations that only the low intensity sections of the 2 min and 3.3 min curves of Fig. 1 can be considered as truly representing intensity discrimination for these small areas.

Discussion

A hypothetical account of the area-intensity relation has been put forward earlier (**3**, **2**). The hypothesis is based on the idea that the excitatory contribution of an elemental area,

$rdrd\theta$, to the threshold effect, E, at the center of the illuminated circle is inversely proportional to a power, p, of the distance from the center, r. Thus, excitatory contribution, dE, is proportional to $1/r^p$. The threshold, by this hypothesis, is determined when the excitatory effect at the center reaches a critical value.

From an experimental observation it may be inferred that the excitatory gradient is as important for intensity discrimination as it is for threshold. If, while a subject is becoming adapted to the prevailing illumination, I, a flash of light is allowed to fall on the adapting surface, the subject reports a momentary increase in the brightness of the test patch. However, it may be observed that this momentary increase does not take place over the whole patch, but seems to appear at a point, or in a small area. Typically, with good fixation, the locus of the increase in brightness is near the center of the area. This observation seems to indicate that excitation is not uniform over the whole patch, but exhibits a gradient of effect, the greatest effect being near the center of the stimulated area. If we make assumptions similar to those made for the threshold determinations, we may write

$$\Delta E = \Delta e \int_0^{2\pi} \int_0^R \frac{r dr d\theta}{r^p}, \tag{1}$$

where ΔE is the increment in excitation at the center, Δe the increment in intensity effect in the receptor elements, R the radius, and the other terms have the significance discussed above.

Equation (1) may be given more specific form if we assume that e is proportional to x, the concentration of photoproducts broken down by light. Under these conditions, with k a constant of proportionality,

$$\Delta E = k\Delta x \int_0^{2\pi} \int_0^R \frac{r dr d\theta}{r^p}. \tag{2}$$

This expression on integration becomes

$$\Delta E = \frac{2\pi k R^{2-p}}{2-p} \cdot \Delta x. \tag{3}$$

The simplest assumption we can make with respect to the discrimination threshold is that it is constant (*i.e.*, ΔE = constant) and equation (3) for this specific case may be written

$$C = \Delta x R^{2-p}, \tag{4}$$

where

$$C = \frac{(2-p)\Delta E}{2\pi k}.$$

In terms of Hecht's theory of foveal intensity discrimination for human subjects (Hecht, 6; Graham and Kemp, 5)

$$\Delta x = k'\Delta I(a - x)^2, \tag{5}$$

where $k' = k_1\tau$, τ being the duration of the ΔI flash, a constant in our experiment. When we substitute the right hand side of (5) for Δx in equation (4) we have

$$C' = \Delta I(a - x)^2 R^{2-p}, \tag{6}$$

in which $C' = \frac{C}{k'}$.

In order to test our data it is necessary to find an expression for $(a - x)$ in terms of intensity. This may be done by observing that the stationary state equation for human retinal adaptation to I states that $KI = \frac{x^2}{(a - x)^2}$. Solving for $a - x$ gives us the expression $a - x = \frac{a}{1 + (KI)^{\frac{1}{2}}}$; and if this equality be substituted for $a - x$ in (6) we obtain

$$c\Delta I R^{2-p} = [1 + (KI)^{\frac{1}{2}}]^2, \tag{7}$$

where $c = \frac{a^2}{C'}$. On dividing both sides of (7) by KI we arrive at our test expression:

$$\frac{\Delta I}{I} \cdot R^{2-p} = \frac{K}{c}\left[1 + \frac{1}{(KI)^{\frac{1}{2}}}\right]^2. \tag{8}$$

This equation is similar in form to Hecht's expression except that it involves, on the left hand side, a term for area (or radius). With area constant this term is contained in K/c. The important implication of this development is that, with

the proper value of $2 - p$, a plot of $\log \frac{\Delta I}{I} \cdot R^{2-p}$ against $\log I$ should be fitted by an expression similar in its intensity parameter to Hecht's theoretical equation.

This test is shown in Fig. 2. In this figure the averaged $\log \frac{\Delta I}{I} \cdot R$ values for our two subjects have been plotted against $\log I$; the line drawn through the data is the curve of equation (8). It may be seen that the data are fitted reasonably well by this formulation. Strictly, of course, the hypothesis would

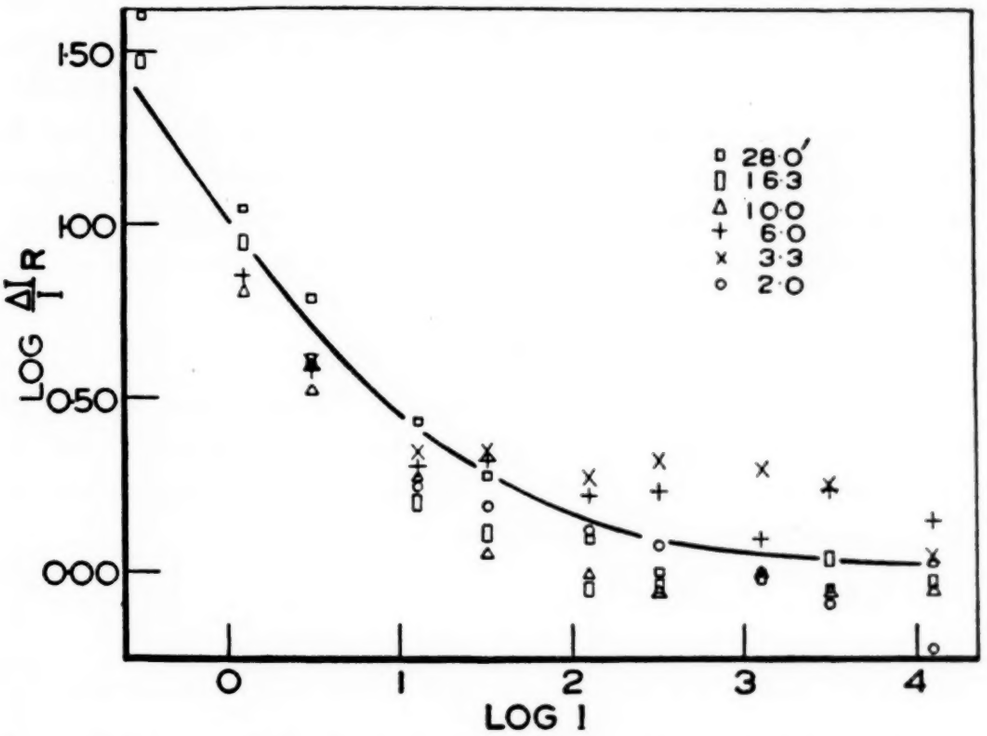

FIG. 2. The averaged data for the two subjects plotted in terms of the requirements of equation (8). The curve is theoretical.

require that the curves of Fig. 1 should be parallel along the ordinate. We have pointed out that this is not so, and that their positions involve a slight displacement along the abscissa axis. However, the effect is small, and to a reasonable approximation the formulation of equation (8) may be accepted as accounting for the data. Certainly, the expected relation holds within limits which are close to the normal variability of the data. The lack of parallelism, then, is not serious, but it should be kept in mind.

The treatment as outlined accepts a value of *unity* for $2 - p$ in equation (8). This is not the value found in the experiments on threshold (**3**, **2**). In those experiments it turned out that $2 - p$ was close to 0.5. The value for the present experiment is based upon a more certain theoretical foundation than is true for the threshold determinations where results were obtained with an approximate expression for e, viz., $e = k \log I/I_0$. The numerical doubling which would be required in order to make the threshold value of $2 - p$ agree with that of the present experiment might be due, in the threshold experiments, to the use of a term not proportional to e, but to its square root. Such a factor would remain unknown by the method used for the determination of constants in the earlier experiments, *i.e.*, a plot of log log I/I_0 vs. log R. The value of $2 - p$ in the two groups of experiments remains a discrepancy, and further critical experimentation will be required before the difficulty it presents can be resolved.

Summary

1. Foveal intensity discrimination thresholds have been obtained with white light over a range of 4.6 log units of adapting intensity (I) and for circular areas varying in radius from 2 to 28 minutes of visual angle.

2. With a constant area of stimulus surface, the ratio $\frac{\Delta I}{I}$ has a high value for low intensities of I. As I increases, $\frac{\Delta I}{I}$ decreases and finally reaches a limiting value at a high level of adapting intensity.

3. At comparable levels of adapting intensity, I, the ratio $\frac{\Delta I}{I}$ is large for small areas and decreases as area increases.

4. The results are described approximately by means of a combination of hypotheses: one in terms of retinal photochemistry (**6**) and the other in terms of visual spatial effects (**3**, **2**).

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CORTICAL AUTONOMOUS RHYTHMS AND THE EXCITATION LEVELS OF OTHER BODILY TISSUES

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In this discussion we shall use the term *cortical autonomous rhythm* to mean those 'spontaneous' bioelectrical discharges obtained by connecting electrodes on the scalp to a sensitive amplification system and an oscillograph. By the term *excitation level* we mean the degree to which a given bodily tissue or group of bodily tissues is aroused. In one sense of the term excitation level is used synonymously with metabolism, for a highly excited or active tissue is one which is metabolizing rapidly.[1] But the term metabolism is usually applied to some measure of general energy cost, such as oxygen consumption, that is supposed to summate the total or near total of all tissue excitation. We have previously reported that two measures of general metabolism are a relatively crude (**9**) and, at times, an indifferent index of the excitation level of different bodily parts and systems (**6**). Lately, various attempts have been made to secure indicators that are influenced mainly by the excitation level of bodily tissues used primarily in higher behavioral adjustment. Thus the palmar skin resistance has provided a useful index of skeletal muscle tensions (**8**) and autonomic changes (**2**) associated with 'alertness' functions of the central nervous system. Muscle action potentials are an index of more localized tissue activity, and, it appears, so are the cortical autonomous rhythms. Jasper (**11**) and others have already suggested that both the frequency and the amplitude of the 'alpha rhythm' are an index of the 'excitatory state' of cortical cells; and Williams

[1] To be exact, however, we should mention that 'metabolism' usually refers to the basal life processes of cells independent of the influx of stimulation to them (which, of course, raises their metabolic activity). An excitation level of a tissue is its basal life processes as raised or depressed by neural or humoral influences of other origin.

(**16**) and others have used 'percent time alpha' as if it were an index of cerebral excitation.[2] The evidence comes from various lines of research on intact human organisms, and is consequently indirect and confused. The purpose of this report is to contribute some new observations on the correlation, under a variety of conditions, between percent time alpha and measures of the excitation level of other bodily tissues, as measured by palmar skin resistance and muscular action potentials, which are associated with 'alertness' functions of the central nervous system.

Existing studies show that cortical autonomous rhythms are influenced by excitation of external origin (such as visual stimulation) and of internal origin (such as changes in body temperature). Methods of approach usually vary either the external or internal factors separately, while attempting to hold the others relatively constant. A few attempts have been made to correlate measures of general excitation level (*i.e.*, metabolism) with frequency of cortical autonomous rhythms in different subjects. In reviewing this work, Jasper states that the recordable alpha rhythm may be confined to a fairly limited range of cortical excitation, *i.e.*, with the subject resting quietly, and with activity connected with external stimulation relatively absent (**12**). The possible reason for the absence of recordable rhythms at these extremes is that a decrease in the cortical excitatory state causes an 'anode' depression of the spontaneous cortical potentials and hence a depression of the alpha frequency, while a sufficient increase in cortical excitation causes excessive polarization charges in the tissues and so produces 'cathode' blocking of the rhythmic frequencies. The fact that spontaneous discharges in isolated nerve fibers are affected in an analogous manner by excitation superposed upon their basal metabolic activities lends support to the argument that cortical autonomous rhythms are con-

[2] In the writer's opinion, Jasper's concept of 'excitatory state' is partially tied up with the basal metabolic activity of cortical cells, and partly with their threshold or readiness to respond. To the extent that a raised 'excitation level' indicates a lowered threshold, it would seem that Jasper's 'excitatory state' and our 'excitation level' are related concepts. Alpha rhythm, however, is one of a continuum of cortical frequencies and it is doubted in some quarters if it can be meaningfully studied apart from the total cortical energy flux.

fined between certain excitation limits. Beginning with conditions of extreme excitation, as with intense exteroceptive stimulation and internal emotional arousal (where there are no rhythmic potentials), the series presumptively follows through states of moderate excitation with high-frequency, low-amplitude potentials, occasionally synchronized, and moderate relaxation with low 'alpha' frequencies and beginnings of irregularity, to end in deep sleep with very slow random swings in electrical potential. Not only would this series seem to hold for a given subject, as indicated by shifts in alpha frequency due to experimental alteration of body temperature and thyroid balance, but also it appears that individual differences in cortical rhythm may have similar bases. Thus Davis (**3**) and many others have reported that the more rapid alpha frequencies appear in patients who might be classed as highly excitable, and Lindsley and Rubenstein (**14**) have found rather high correlations between the frequency of 'alpha' and basal metabolic rate (**6**). Leaving out of account for the moment the known effects of external stimulation in 'knocking down' the rhythm, it appears that the control of cortical autonomous rhythms (or of the general cortical states which produce them) depends upon the excitation level of other tissues acting as 'pacemakers.'

It is at this point that our own experimental attack arises. Previous work has paid little attention to concomitant changes in other tissues when examining the encephalographic records for the influence of various stimulus conditions. Study needs to be made of muscular tension and other 'alertness' indicators, especially since such reports as those of Williams (**16**) suggest that the Jasper hypothesis (alpha blocking at high excitation levels *per se*) may be untenable, because "the percent time alpha obtained when the eyes are closed can also be obtained or approached, by facilitating, by the induction in the subject of a state of readiness, the alpha rhythm when the eyes are open."

In our experiments we have recorded electroencephalograms concurrently with palmar skin resistance and muscle action potentials when both the internal preparation and ex-

ternal stimulation were varied.[3] Results suggest that cortical autonomous rhythms depend upon the dynamic balance in the brain field of asynchronous excitation of external origin and of synchronous excitation associated with, and sustained by, muscular tension and other preparatory tissue activities.

The Experiments

Subjects were placed on a cot in the shielded, soundproofed dark room and instructed to relax and go to sleep if they could. After a period of fifteen to thirty minutes (depending upon the experimenter's estimate of the lowest general excitation level probable in the situation) a series of electric shocks or light flashes was introduced (initially sub-threshold but of geometrically increasing strength). When the series was completed (in five minutes), the aroused subject was asked to relax again; and after another fifteen minutes he was told to push slightly with his feet against levers so as to develop and maintain some general muscular tension during the next five minutes, after which the original series of stimuli was again applied. Then followed five minutes of rest, the total session lasting about forty-five minutes. Electroencephalograms, muscle action potentials from the arm, and palmar skin resistance were recorded simultaneously throughout the observations. The encephalograms were obtained from small solder electrodes attached to the occiput with collodion and connected to a high-gain resistance, capacity-coupled amplifier activating a magnetic ink-writer. The palmar skin resistance level was recorded in standard ohmic units from a wheatstone bridge circuit using nine volts as external current. The muscle action potentials were obtained from small copper plate electrodes connected through a resistance coupled amplifier to an electrical integrator (**10**) which summated total deflections (amplitude and frequency of potentials) over an arbitrary time unit.

In general, it was found that the percent of time the alpha rhythm appeared in the encephalograms paralleled changes in the excitation level of skeletal muscle and autonomic tissues during conditions of rest and experimentally induced tension. Introduction of external stimuli tended to increase or decrease the activity of the cortical cells, depending upon whether the excitation level of the postural or preparatory tissue activities was enhanced or depressed.

As representative of the trend of our results, we publish in Fig. 1 curves of one subject showing the concurrent changes of cortical activity, palmar skin resistance, and muscle action potentials occasioned by the experimental routine. In the figure, measures of physiological response have been plotted

[3] Our attack is to be contrasted with that of T. W. Forbes and H. L. Andrews (*Science*, 1937, 86, 474–476), who found some evidence in favor of the independent control of the *psychogalvanic* (*reflex*) *response* and the blocking of cortical autonomous rhythms. Our correlations are based upon the slower acting changes in *resistance level*.

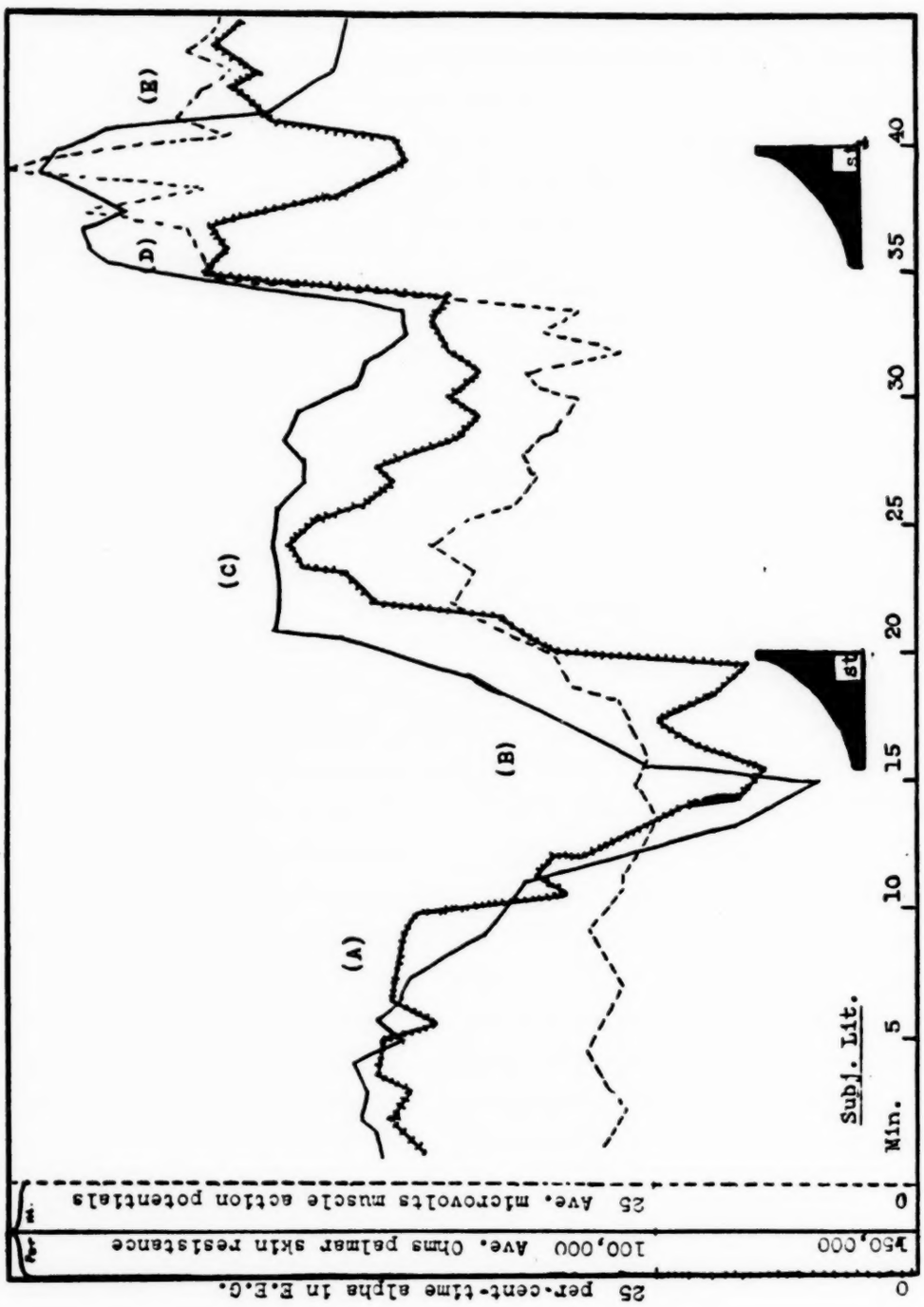

FIG. 1. Concurrent changes in E.E.G., palmar skin resistance, and muscular action potentials under various conditions of alertness (see text).

so that a rise in a curve will indicate a supposed increase in the excitation level of the tissue or tissues concerned; thus, the greater percent time alpha (within limits), the greater the assumed excitation level of cortical cells; and the lower the palmar skin resistance, the greater the responsible autonomically controlled activity. Percent time alpha is determined by dividing the greatest number of alpha waves which occurred in a given minute of record by the number which could possibly have occurred. The resistance readings are averages for several periods. The muscle action potential readings are in terms of average microvoltage effects per minute.

The inter-relations of the three measures of bodily excitation shown in Fig. 1 require interpretation. Whereas the palmar skin resistance and the E.E.G.'s are often parallel, there are many instances where an increase in the activity of one bodily indicator is accompanied by a decrease in the other. These shifts in trend may be studied conveniently by reference to five portions of the experiment. During the first few minutes of rest (as in *a*) the E.E.G. has stabilized itself at the level of about 52 percent time alpha; but the palmar activity, slowly decreasing, drops very rapidly during the last five minutes as the subject presumptively begins to fall asleep. In the relative absence of stimulation from internal bodily tissues, the cortical excitation level also falls. Against this background of general relaxation, external stimulation is introduced in the form of weak electric shocks (as in *b*) and the first effect is to raise the cortical excitation level with consequent increase in percent time alpha. However, as external stimulus strength increases to a point where postural preparatory acts fail to keep pace, the dynamic balance of cortical potentials is disturbed and the alpha rhythm falls off. When external stimulation is removed (as in *e*), however, the residual excitation contributed by internal tissues acts to sustain the cortical field in a state where the alpha rhythm will again predominate. S is now 'alert,' as contrasted with his previous 'drowsiness,' but after a period passes and there is no more external stimulation, he begins to relax until told to tense his muscles and get ready for stimulation again (as in *d*). This internal prepara-

tion tends to increase the alpha rhythm, but when accompanying external stimulation is also increased sufficiently, percent time alpha falls. With stimulation removed (as in *e*), cortical dynamics are again such that more alpha is recorded. Throughout the experiment, from *a* to *c* to *e*, there has been a rise in the absolute level of percent time alpha as general bodily excitation (subcortical pacemakers?) rises under the increased 'alertness' demands of stimulation. It might be argued that the absolute changes in our E.E.G. records are not significant since percent alpha is often reported [4] to vary as

TABLE I

PERCENT CORTICAL ALPHA RHYTHM (E.E.G.) AND MUSCULAR MICROVOLTAGES (A.P.) DEVELOPED UNDER THREE STATES OF BODILY EXCITATION, (*a*) MODERATE RELAXATION, (*c*) 'ALERTNESS' FOLLOWING EXTERNAL STIMULATION ALONE, AND (*e*) 'ALERTNESS' FOLLOWING STIMULATION PLUS VOLUNTARILY INDUCED MUSCULAR TENSION.

Subject	Condition *a*		Condition *c*		Condition *e*	
	E.E.G.	A.P.	E.E.G.	A.P.	E.E.G.	A.P.
Lit.....	52%	30.5Mv.	60%	45.0Mv.	65%	63.1Mv.
May.....	58	25.6	57	47.3	65	85.1
Fri.....	17	61.0	—	65.9	—	107.0
Hof.....	70	10.8	63	15.0	55	29.5
Kra.....	12	80.6	15	127.7	20	170.0
Rea.....	32	27.8	38	30.4	44	58.4
Sch.....	48	36.2	55	28.0	61	73.8
Cli.....	74	75.5	—	87.3	—	125.1

much under the same conditions of rest. Perhaps, however, these 'same' conditions actually included concurrently undetected variations in postural activities similar to those demonstrated in our experiment.

Results similar to those represented in Fig. 1 have been obtained with graded light stimuli substituting for electric shocks; and in five out of the eight subjects used, the trend toward higher percent time alpha in E.E.G.'s with increased general bodily excitation has been in evidence. Detailed analysis of Table I, however, would indicate that a better relationship exists between E.E.G. and A.P. under conditions of external stimulation alone (*c*) than under a combination of ex-

[4] D. B. Lindsley, in personal communication with the writer.

ternal stimulation and internal (tension) excitation (*e*). Consequently, it is possible that backlash propnoception may influence cortical frequency only over a limited range. It is regrettable that we did not have measures of total cortical energy changes, as amplitude rather than frequency factors may be more influenced by the concurrent activity of other tissues.

No special significance can be attached to the difference between individual readings, since they may be due largely to such external factors as placement of electrodes. In fact, we feel that it is much too early, even, to advance any formal hypothesis covering differences in trend from subject to subject. On the surface it appears as if subjects with initially low muscular activity show a trend toward increased alpha rhythm with increased postural preparation. Contrawise, some of the subjects with a higher degree of initial muscular activity vary little from condition *a* to condition *c* and gain little or no change in cortical alpha frequencies.

Discussion

The interpretation of our results is greatly handicapped by inadequate knowledge about the fundamental nature of the physiological processes we have recorded. Of the three, the nature of the encephalogram is most problematical, so we shall use the electrical responses of the muscles and the skin resistance measures as a basis for the possible explanation of associated changes in cortical processes.

The phenomena which we have measured are changes in the relative amount of synchronization (percent time alpha) in cortical action potentials. Several theories have been advanced to explain this synchronization or 'autonomous rhythm.' That of Jasper, which favors the synchronization within a limited range of cortical excitation, and which has already been discussed, gives no insight into the possible mechanisms by which a given level of excitation is achieved or maintained. Available evidence seems to favor the view that, whereas synchronous electrical discharge may be a property of cortical cells apart from impulses from other

sources (**13**), such autonomous activity may be enhanced or diminished by subcortical 'pacemakers' (**1**) and external stimulation. It has been suggested that the usual effect of visual and other sensory stimuli in 'knocking down' the alpha rhythm is due to direct interference with the autonomous activity of cortical cells caused by the passage of many asynchronous potentials to or through them. The only way, then, in which synchronous discharges could be maintained in a sufficient number of cells to influence the total electroencephalogram would be through a compensatory enhancement of cortical autonomous activity brought about through activity of subcortical coördinating processes responsible for initiating or sustaining the rhythm. Theoretically, it should be possible for these organic 'pacemaker' processes to increase proportionately as interfering stimulation increases and so maintain a more or less constant level of synchronous activity in the total electroencephalogram. But in actual practice, no such exact compensatory grading would be possible, and external stimulation would more frequently than not increase local asynchronous cortical excitation to such a level that the alpha rhythm would disappear from a record. The fact that bodily conditions prior to and following such stimulation are frequently accompanied by an increase in percent time alpha (**15, 5**) supports the view that other pacemaker tissue activities, in the absence of external stimulation, increase the prevalence of cortical autonomous rhythms. If this is true, then the Jasper hypothesis should be restated to indicate that autonomous rhythms are not 'knocked down' by absolute changes in the level of cortical excitation *per se*, but fail to appear either when the activity of 'pacemaker' tissues and circuits gives insufficient reinforcement to these natural discharge rates or when asynchronous excitation of external origin sufficiently interferes with their influence on the total electroencephalogram.

Our results offer some support to this latter hypothesis. When an individual is made more alert (as following excitation from a background of relaxation, or when prepared to meet stimulation with increased muscular tension) not only does

the percent time alpha increase, but so also do autonomic and skeletal processes already known (**5**) to be facilitatory to performance. In other words, those bodily processes which have a reinforcing backlash influence on higher nervous activity, also appear to increase (in the relative absence of interfering exteroceptive discharges) the prevalence of cortical autonomous rhythms. Thus it may be that the fundamental 'pacemakers' of cortical rhythms, are, in fact, those same postural activities whose dynamogenic effects have been so often acclaimed by 'motor' psychology (**4**, **6**). Earlier evidence has already shown that individual differences in alpha frequency are related to such measures of general bodily excitation as metabolism. Our results give an indication that, within the same individual, the prevalence of cortical rhythms tends to parallel increments in the excitation level of sustaining postural activities. We accordingly suggest that the percent time alpha, prior to or following external stimulation, may become a useful quantitative measure of the excitation level of the higher nervous centers. It is possible that an even closer relation between E.E.G. and general alertness would have appeared had amplitude changes been substituted for percent time alpha.[5] Further checks of the hypothesis should use both measures.

Several difficulties appear in making cortical autonomous rhythms a direct function of motor activities which help maintain the excitation level of cortical cells. Williams,[6] who

[5] Our recording equipment, unfortunately, precludes valid statements on the influence of postural preparation on the amplitude of E.E.G.'s, but we have searched our records for change in *alpha* under increased bodily alertness, and have failed to find any valid evidence for increments in its rate *per se*. The data have not been analyzed with respect to 'beta' and other frequency changes.

[6] Williams' (**16**) alternative hypothesis, namely that pacemaking impulses associated with alertness might increase cortical synchronization by inhibiting the interfering asynchronous impulses of external stimuli origin, may be questioned on the grounds that enhancement occasionally occurs when the interference of asynchronous visual stimulation is still operating. Of course a reinforced alpha rhythm might 'inhibit' the influence of stimulation on total field activity by 'blocking out' or 'over riding' asynchronous discharges of lower amplitude. The fact that depression of alpha activity by external stimulation is apparently more a decrease in amplitude than a change in frequency suggests quantitative management of the electroencephalogram similar in character to that found at the spinal level.

has favored an hypothesis somewhat similar to the one here expressed, has mentioned the fact that severe emotional (motor?) activity may cause a decrease in alpha frequencies rather than an enhancement. Furthermore, he states, the theory is too easy to apply, as when "the record during sleep would be interpreted as a cessation of the activity of the pacemakers . . . and stimulation with an arousal value would momentarily activate the pacemakers." To this we should add that it is difficult to conceive how postural or preparatory activities could enhance the percent time alpha or some related measure of cortical excitation. Certainly the proprioceptive influx is anything but synchronized. However, it is possible that the thalamic centers help to organize backlash 'motor' excitation by 'loop' circuits (1) to the cortex which pass impulses only at certain phases of their rhythmic activity. A further supposition, namely, that if the incoming flux were too great, it would escape the bounds of these coordinating circuits and discharge asynchronously with the cerebral cortex, might explain the depressing effect on E.E.G. of intense 'emotional' excitement.

With so little known about the intimate details of cortical dynamics, it may seem premature to attempt an explanation of autonomous rhythms in terms of the excitation levels of supporting postural tissues. But the virtue of any hypothesis is not its ultimate truth or falsity, but its capacity to bridge gaps in present knowledge and suggest experimentation. Viewed in this light, the suggestion that autonomous rhythms roughly indicate the cortical excitatory condition operating as a 'tonic' background for external 'phasic' stimulation has much to commend it. A convenient means is offered for organizing electroencephalographic data in experiments which vary the bodily condition, set, or alertness functions of the individual; and another way is thereby opened for determining the efficacy of 'pacemaker' theories.

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THE EFFECT OF INSTRUCTIONS AND TYPE OF TASK UPON ANTITROPIC BILATERAL MOVEMENT

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The theory proposed by Orton (**11**) in 1925, that lack of lateral cerebral dominance is the physiological basis for reading and speech disorders, stimulated numerous studies on lateral preference and priority of response when homologous muscle groups are simultaneously contracted in similar movements. The assumptions underlying the theory and experiments were (*a*) that the more dominant hemisphere should be associated with a laterality preference as indicated by a handedness questionnaire and a corresponding lateral lead when there is an attempted simultaneity of response; and (*b*) conversely, that tests of lateral preference and lead should indicate the degree of dominance of one hemisphere over the other. According to Orton's theory, simultaneous discharge from the two cerebral hemispheres is symptomatic of a lack of dominance and should be accompanied by an interference between the two sets of neural impulses, resulting in stuttering, reading disabilities, and perceptual confusions.

This hypothesis seems to have been elaborated, in part, from an observation by Golla (**4**). He found that when a left handed subject attempted to move both arms at the same time action currents always arrived first in the left arm muscles. Moreover, when S was instructed to move only the left arm, action currents appeared only in the left side; but when he was instructed to move the right arm, action currents were noted first on the left side, although only the right arm moved. Following this experiment the theory rapidly developed that lateral leads could be used to indicate the degree of lateral cerebral dominance.

In the experiments by Orton and Travis and others that have followed the tasks required of the subjects in determining

motor lead have been essentially similar to that required of Golla's subject. The situation confronting the subject in most of these experiments is not unlike that of the usual reaction time experiment. In a typical experiment, the subject is instructed that at the flash of a light he is to depress instantly and simultaneously the two telegraph keys respectively below right and left forefingers. Records are taken of frequency and temporal extent of lateral priority of response. As a test for revealing type and extent of lateral cerebral dominance the results were disappointing. Some experiments showed little consistency of lead for either right or left sides, while other experiments revealed the more frequent leads to be associated with the non-preferred side.

That the subject's conception of the task to be performed was important in determining lateral priority of response was shown by Warren and Metfessel (**10**) and Warren (**16**). They found that the subject tended to overcompensate with the side perceived as weaker. Thus, when forefinger of one hand and little finger of the other hand were used to depress the keys, records indicated the little finger as more frequently leading regardless of general handedness. This, in part, explains the earlier observations that the non-preferred side more frequently leads.

Following this experiment Travis, Tuttle and Bender (**15**) attempted further to isolate the effect of instructions on precedence of movement. They studied leads under three different conditions as follows: I. At a light signal S raised both arms. He was not instructed to attempt simultaneity of movement. One may not be warranted, of course, in assuming that S did not attempt simultaneity of movement. II. In this series S was specifically instructed to move both arms at the same time. III. Response of S was the same as in I and II, but the stimulus or signal was made more complex in order to dominate attention.[1] Results of Series I and II indicated an approximately equal distribution of leads between right and left sides; while the results of III showed leads

[1] The purpose here is essentially to distract the subject's attention from the response in the hope that basic physiological organizations may be revealed. *Cf.* Jasper's use of distraction (**6**); also Series II of the present experiment.

both in frequency and temporal extent to be associated with usual side preference.

Statement of Problem

Thus far all experiments in which frequency and temporal extent of motor leads have been studied have set the conditions essentially similar to the reaction time experiment. Regardless of explicit instruction the nature of the task required by the apparatus or total experimental situation may operate to structure the subject's psychological field so that compensatory tendencies are elicited. These tendencies seem, in the long run, to favor the non-preferred or weaker member. Thus, if there are basic physiological mechanisms or tendencies they may become obscured. The purpose, therefore, of the present experiment is to isolate the effects of instructions and type of movement upon motor leads when continuous antitropic pronation-supination movements are contrasted with discrete movements of the same character.

Apparatus

The apparatus used and the type of record obtainable have already been described in two previous articles.[2] Rotary forearm movements, *i.e.*, pronation-supination, are transmitted directly to a rapidly moving kymograph paper. The action of the record markers is always in the plane through which the paper moves and per-

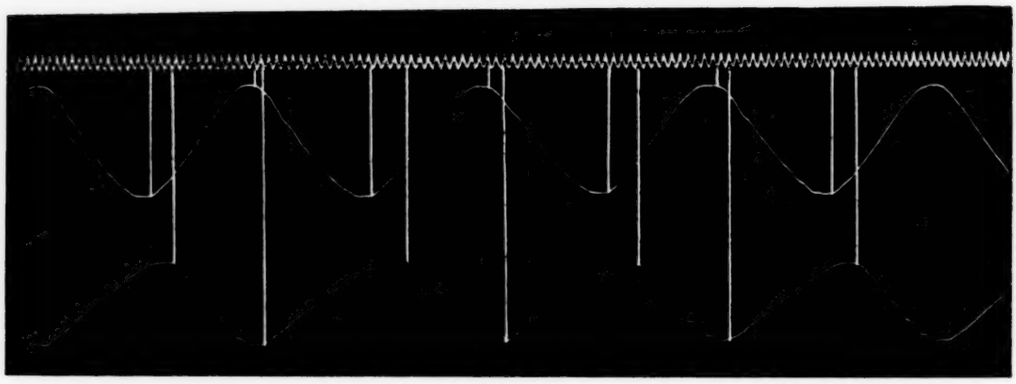

Fig. 1.

pendicular to the direction of its motion. Since accurate alignment can be maintained between the writing points, a time analysis can be made of right and left forearm movements when records are taken simultaneously. A Joseph Becker time marker driven by the 60 cycle current permitted a time line unit of 8.3 milliseconds. Figure 1 shows

[2] This *Journal*, 1937, **21**, 181–193; also 1938, **23**, 26–44.

a typical record. The upper tracing was produced by right forearm rotations; the lower tracing is from similar movements for the left. When the tracings are approaching the common center, both arms are pronating; when the tracings diverge, the arms are supinating. Temporal differences in the initiation of either bilateral pronation or bilateral supination may be measured as indicated in Fig. 1. Vertical lines drawn upon the records show how motor leads may be identified and measured. These tracings illustrate a consistent right lead, although the lead is more evident in supinating than in pronating.

Method

Ten left handed and eighteen right handed subjects [3] from college classes were tested under four types of conditions. I. Subjects were instructed to rotate (pronate-supinate) both forearms as rapidly as possible from a signal 'Go' until told to stop. The duration of a work period was 20 seconds. No suggestion was given to synchronize movements. II. This series was the same as I with the exception that the subject was asked to read aloud a series of sentences during the work period. III. In this series the instructions were altered so as to simulate in part the situation of the usual motor lead test. The subject was required to make each pronation and each supination a discrete movement. The subject was urged to synchronize the movements of the two arms by initiating the movements in each direction at the same instant. The movement in a given direction was to be as rapid a movement as possible, but he must start each movement with both arms at the same moment. IV. This series was designed to test the effect of a prolonged work period upon motor leads. Instructions and task were the same as in Series I, except that a 40 second work period preceded the record.

Results

Table I presents a brief summary of results obtained from the twenty-eight subjects. It is evident that under conditions of Series I, II, and IV frequency of lead is associated with lateral preference. The important finding revealed in this table, however, is the contrast between Series III and the

TABLE I

Percentages of Lateral Leads for Right and Left Handed Individuals under Four Sets of Conditions

	Right Handed (18 Subjects)		Left Handed (10 Subjects)	
	Right Leads	Left Leads	Right Leads	Left Leads
I. Continuous movement.	83.3	16.7	7.3	92.7
II. Continuous movement plus reading.....	77.3	22.7	18.5	81.5
III. Discrete movement....	56.5	43.5	45.4	54.6
IV. Continuous movement plus fatigue.....	85.5	14.5	12.2	87.8

[3] Laterality classification was determined by a handedness questionnaire similar to those used by Koch (**8**) and Durost (**3**).

other variations. Under conditions of Series III, leads seem to be almost equally distributed bilaterally for both right and left handed subjects. These data are similar to the results obtained from the usual motor lead experiment. It is evident, therefore, that type of instructions and task are important in determining which of the two sides initiates the response in an attempted simultaneous movement. The results indicate, furthermore, a consistent lead associated with lateral preference when neither explicit nor implicit instructions direct the attention of the subject toward attempting simultaneity in the initiation of bilateral responses. In the usual motor lead experiment implicit instructions, due to type of task, appear to direct the attention of the subject toward simultaneous initiation of movements regardless of explicit instructions. When the data are classified as precedences for either right or left sides, frequencies of leads in terms of their magnitudes are not revealed. The results of the present experiment indicate that these relationships cannot be overlooked.

TABLE II

Table II is a frequency distribution of leads according to their temporal magnitudes. Multiplying scores by 8.3 translates them to milliseconds. Left leads for the right handed subjects are treated as negative quantities while right leads for left handed subjects are treated as negative quantities.

Scores	Right Handed				Left Handed			
	I	II	III	IV	I	II	III	IV
18 to 19.9				3		1		
16 to 17.9				4		1		1
14 to 15.9	4	1				1		
12 to 13.9	1	5		3	2	6		2
10 to 11.9	2	8		3		6		3
8 to 9.9	16	24	2	10	11	8		9
6 to 7.9	24	24	3	23	16	19	7	45
4 to 5.9	82	54	17	40	72	37	13	62
2 to 3.9	127	94	63	102	161	66	45	34
0 to 1.9	107	55	81	70	113	32	87	32
−2 to −0.1	48	42	79	24	16	21	63	13
−4 to −2.1	16	28	27	19	14	10	37	11
−6 to −4.1	7	8	13	1		4	12	2
−8 to −6.1	2		6			3	9	
−10 to −8.1			3				5	
Total no. of measures	436	343	294	302	405	205	278	214

Table II presents a frequency distribution of leads classified according to their temporal magnitude. The score values have been left in their original units, each unit representing 8.3 milliseconds. For right handed subjects, left leads have been classified as negative quantities. Similarly, the right leads of the left handed subjects have been classified as negative. The symmetry of the distribution makes it evident that separate classifications for right and left leads are rather artificial and can be misleading.

TABLE III

Values in Table III are statistical derivations of Table II. Units are 8.3 milliseconds.

Series	Right Handed			Left Handed		
	Av.	S.D.	$\sigma_{av.}$	Av.	S.D.	$\sigma_{av.}$
I	2.66	3.24	.155	2.80	2.36	.118
II	3.00	3.63	.196	3.38	4.25	.297
III	0.34	2.96	.173	−0.85	3.19	.192
IV	3.10	3.80	.218	3.74	3.60	.246

TABLE IV

Table IV presents critical ratios found by computing the standard errors of the differences between the averages of the pairs of Series indicated in the table.

Right Handed Subjects		Left Handed Subjects	
Series	C.R.	Series	C.R.
I– II	2.64	I– II	1.80
I–III	10.00	I–III	16.30
I–IV	1.65	I–IV	3.43

The data of Tables III and IV are statistically derived from the frequency distributions of Table II. These data permit a rapid comparison of the behavior of motor leads under the four variations of conditions. Table IV gives the critical ratios of the differences between the averages for the series or variations indicated. The data show, even more clearly than Table I, the striking contrast between Series III and the others.

Figures 2 and 3 are included to illustrate further this contrast. The superimposed curves are made directly comparable by letting each point represent a percentage of the total distribution.

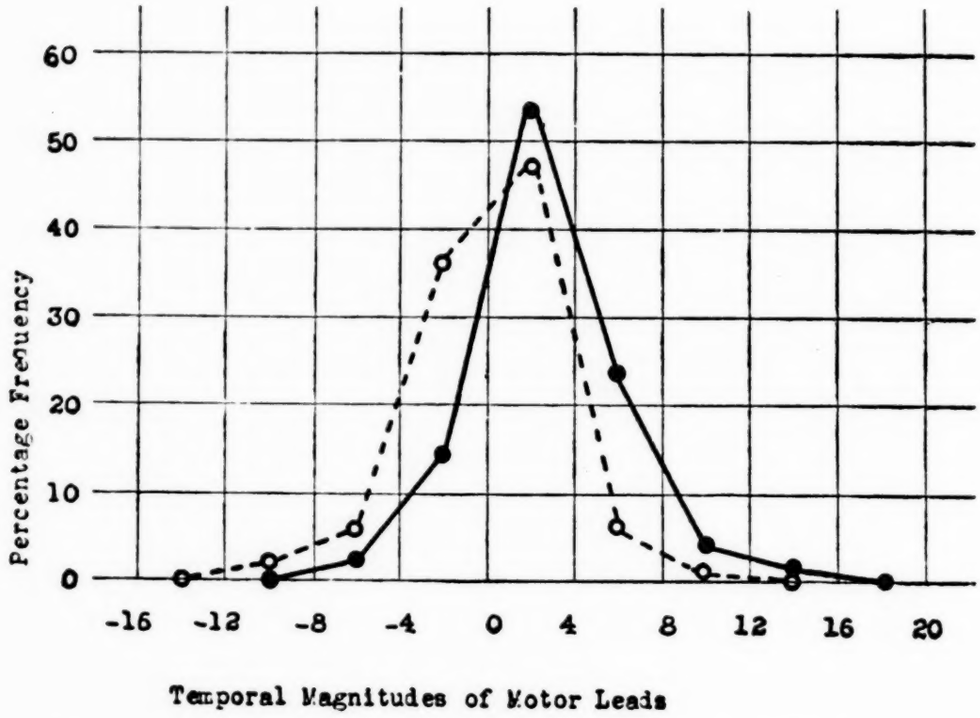

FIG. 2. Presenting a comparison of lateral lead frequencies under the two conditions of Series I and III for right handed subjects. Solid line—Series I; dash line—Series III. Negative values represent left side leads. Time units equal 8.3 milliseconds.

DISCUSSION

1. *The Effect of Instructions and Type of Task upon Simultaneous Bilateral Performance*

In all of the tables presenting results the sharpest contrasts are found between Series III and the others. Only in Series III were task and instruction of the nature that would direct attention of the subject toward attempting to initiate bilateral movements at the same instant. This series was designed to approximate the type of task and instructions employed in the usual motor lead experiment. Each bilateral pronation and each bilateral supination was to be initiated at the same instant. In the other series the instructions were designed to elicit rapid, continuous reciprocal movements. The attention

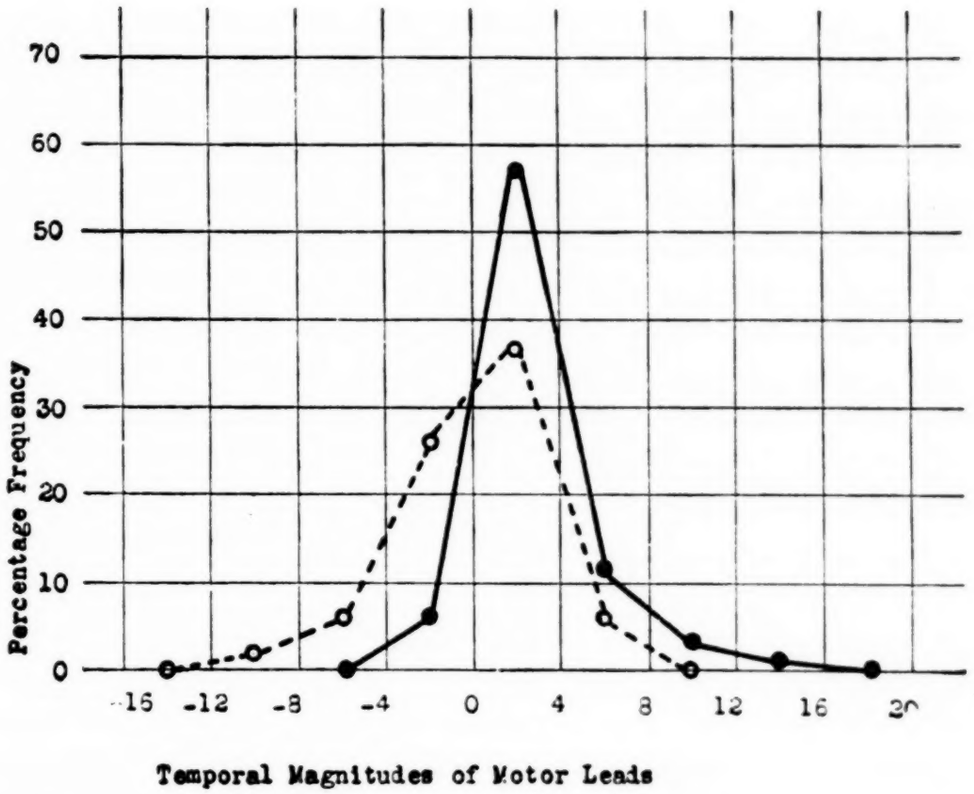

FIG. 3. Presenting a comparison of lateral lead frequencies under the two conditions of Series I and III for left handed subjects. Solid line—Series I; dash line—Series III. Negative values represent right side leads. Time units equal 8.3 milliseconds.

of the subject through both instructions and type of task was directed toward speed of movement. It is of importance to emphasize that, regardless of explicit verbal instructions offered by the experimenter, the type of task may involve certain implicit instructions which the experimenter may overlook. Furthermore, it appears to be quite possible that these implied instructions may nullify, in part, the experimenter's explicit instructions. In other words, preparatory states for action are derived from the total field to which the subject responds rather than from segments of that field, *e.g.*, an experimenter's verbal instructions. Therefore, if the experimenter would have his subject avoid an attitude out of which would grow an attempted simultaneity of bilateral response with a probable tendency to 'compensate for perceived weakness' (**16**, p. 593), then the nature and meaning of the task set for the subject must be considered as well as instructions.

2. *Distribution of Leads*

Table II is a frequency distribution of leads according to their temporal magnitudes. Ordinarily, the right and left leads are sharply separated with a third category for simultaneous leads. Since there usually is only a small proportion of simultaneous leads, this manner of treating the data appears to imply a bimodal distribution of scores in terms of their temporal values. The data of the present experiment indicate quite unmistakably a unimodal distribution when left leads for the right handed individual are treated as negative values and when the right leads for the left handed individual are classified as negative. If frequency polygons are charted for the scores listed in Table II (*Cf.* Figs. 2 and 3), it will be observed that the curves are both unimodal and symmetrical. The writer sees no reason why such data should not be expected to distribute symmetrically. Scores from single individuals have been found also to be distributed both unimodally and symmetrically, although such distributions reveal individual differences in central tendency and scatter.

When no consistent lateral priority of response is found, then this method of treating the data will reveal a central tendency approximating zero. The extent to which a right or left lead tendency introduces an extra-chance factor in the distribution will be shown by the deviation of the central tendency measures from zero.

3. *Correspondence between Motor Lead and Lateral Preference*

Similar to the findings of Golla (**4**, **5**) and contrary to the results of some of the experiments of Travis and his students (**6**, **12**, **13**, **14**), there is in this experiment a correspondence between lateral preference and motor lead. Disregarding Series III, the temporal magnitude of the lead is of the order of 25 to 30 milliseconds. This value represents the approximate central tendency in a distribution which includes both positive and negative values. The standard deviation of these distributions is in the neighborhood of 30 milliseconds. This means that approximately 68 percent of the temporal values are found between zero and 60 milliseconds, or, rather, the range within which the statistically normal values are

found lies entirely on the side of zero corresponding with lateral preference. It must be emphasized that this is not true when conditions are similar to those of the reaction time experiment. Series III permits the implied comparison. In Series III for right handed subjects the lead averages only 2.8 milliseconds with a standard deviation of 24.6 milliseconds. The distribution is approximately equally divided between positive and negative or right and left leads. For left handed subjects the average is −7.0 milliseconds which means that the central tendency was shifted slightly toward the right or non-preferred side. The standard deviation of 26.4 milliseconds indicates that there is a large representation of leads associated with the non-preferred side.

4. *The Effect of Distraction and Fatigue*

In Series II the subject was instructed to read aloud during the work period. The purpose of this procedure was to determine the effect of a distracting task upon the bilateral motor pattern. There seemed to be evidences in the literature (**6, 15**) that when attention is directed away from the bilateral movements the pattern is modified. The assumption apparently is that this would allow the more basic neuromuscular organizations to express themselves. The usual results are not very convincing. Either distraction by this means is not the proper method or there is no neuromuscular organization more basic than the one expressed through the original task. Series II of this experiment revealed no very significant difference from that of Series I. For the right handed group the critical ratio of 2.64 does approximate reliability; the critical ratio for the left handed group (1.80) is considerably less. Both may be the result of chance fluctuations. Evidently, if the original task does not bring out basic neuromuscular organizations, a distracting task does not greatly help.

The purpose of Series IV was to determine the extent to which a prolonged work period would modify the bilateral movement pattern. If a lateral lead is related to muscular power or resistance to decrement, then an extended work period should accentuate it. Table IV indicates that there was a statistically reliable difference between Series I and IV

only for the left handed subjects. The extended work period increased the frequency and temporal extent of left leads. These results suggest that the non-dominant side of the left handed individual is more vulnerable to the effects of work and fatigue than the non-dominant side of a right handed individual. This must remain only a suggestion, since the size of the groups is too small to permit a generalization.

Summary and Conclusions

The present experiment was designed to investigate the effects of instructions and type of movement upon motor leads when continuous antitropic pronation-supination movements are contrasted with discrete movements of the same character. The method included four variations or series. In Series I the subject made rapid continuous pronation-supination rotations of both forearms from signal 'Go' to 'Stop.' Series II was different only in one respect; the subject read aloud. In Series III each pronation and each supination was a separate or discrete movement. The subject attempted to initiate movements in each of the two directions simultaneously. Series IV was the same as Series I except that the work period was extended in order to study the effects of decrement upon motor leads.

The results permit the following conclusions:

1. When bilateral antitropic forearm movements are continuous, frequency and temporal extent of motor lead correspond with the normally preferred side.

2. Both a distracting task and a prolonged work period operate slightly to accentuate this lead.

3. When type of task and instructions require separate or discrete responses rather than continuous movement, there tends in some cases to be no consistent motor lead; in other cases the motor lead tends to correspond with the non-preferred side.

4. With a continuous series of movements the average lateral priority of response is about 25 to 30 milliseconds with a standard deviation of approximately 25 milliseconds.

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GLANDULAR DOMINANCE IN HUMANS

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Whenever investigations have been made on two symmetrically located organs in the body, it has always been rare to find those organs functioning with identical efficiency. Hundreds of studies have been reported in which these bilateral variations were discussed (**2**), so that despite the fact that we have found no studies in the literature on the dominance of one gland over another, we were not surprised to find this asymmetry of function holding for glandular activity as well. From our findings one might safely assert that not only are we generally right- and left-handed, right- and left-eyed, and so on, but that most of us are either right- or left-glanded, and that some of us are what might be considered ambi-glanded. Although we have reason to suspect that there exists a condition of lateral glandular dominance comparable to that of a muscular nature, we shall not at present extend this generalization beyond our data on the secretory activity of the two parotid glands.

The technique which we used for collecting and measuring the secretion has been described in detail in earlier writings (**4**). Suffice it is to say here that we collected the secretion directly from the ducts of the glands by means of small two-chambered discs which were fastened by suction over the mouth of both right and left Stenson's ducts. When the suction is applied to the outer chamber the disc clings tightly to the buccal mucosa and the secretion is free to flow into the central chamber and then out of the oral cavity by means of the slender rubber tubing which leads out from that chamber. The tubing is attached to calibrated pipettes capable of measuring the secretion in hundredths of a cc. The collecting device itself does not affect the flow of secretion or seriously interfere with the mouth movements of the subject. The apparatus is simple and painless and the subjects quickly become adapted to the presence of the discs. Even with discs on both parotids the subjects are able to converse and eat and drink in a normal fashion. Figure 1 is a photograph of a subject with the discs attached to both glands.

The subjects were seated in front of a small table and instructed to assume a comfortable posture. For records of the normal inactivated secretion, the subjects were instructed to avoid excitatory movements of the tongue or throat, except as directed, and to keep their mouths closed. In order that the accumulated secretions from the

other salivary glands might not interfere with the subjects' comfort, they were permitted to swallow at a given signal at the end of every five-minute period. The rate of flow was recorded every minute. A two-hour experimental period was used for most subjects.

Using this technique we studied the bilateral reactions of 78 subjects: 42 males and 36 females.

Our first problem was to investigate the possibility of dominance during the normal resting state; that is, when no extero-stimulation was applied. If during that period there was consistently more than a 10 percent difference between the amount of secretion from the two parotids, the subject

FIG. 1

was regarded as showing a dominance of one gland over the other. Subjects who did not show this 10 percent difference were regarded as ambi-glanded.

For purposes of clarity we shall summarize our results in terms of percentages. Table I represents the percentages of right-, left- and ambi-glanded subjects.

To our knowledge sex differences of a lateral dominance of muscular or sensory function or structure had never been reported. It came as quite a surprise to us to note, therefore, that our data on glandular dominance indicated a possible sex

variation. From the data collected there seemed to be a significant tendency for the males to be better represented in the left-glanded and the females in the right-glanded group. Thus there were about four times as many right-glanded as left-glanded female subjects; and there were about two and one-half times as many left-glanded as right-glanded males. Of course, continued experiments on large numbers of subjects would be necessary before more reliable percentages could be

TABLE I

GLANDULAR DOMINANCE; NORMAL RESTING SECRETION

	Males	Females	Total Number of Subjects
Dominant gland:			
Right	26%	64%	44%
Left	67%	14%	41%
Ambiglanded	7%	22%	15%

ascertained. In a personal correspondence, Dr. E. I. Strongin reported that his recent bilateral studies duplicated our findings of glandular dominance and that he noted similar sex variations. We do not know to what this apparent sex difference may be attributed. Since we would guess that the glandular dominance observed is in part a function of hypothalamic asymmetry, perhaps morphological studies upon male and female cadavers might yield some clue to this problem.

The lateral glandular dominance which we observed for inactivated secretions was maintained in most cases for activated secretions as well. Forty subjects were used for these experiments. Of these, 21 were right-glanded, 15 were left-glanded, 4 were ambi-glanded in the normal resting state. The activating agents we used were gustatory stimuli and the movements of mastication. Of the 21 subjects who were right-glanded without extero-stimulation, one subject was now left-glanded, one was ambi-glanded, and all the others were right-glanded. All of the 15 subjects who were left-glanded without extero-stimulation showed a left-glanded dominance when the secretion was activated. Of the 4 ambi-glanded

subjects who were used in these experiments two were ambi-glanded when the secretion was activated; one showed a greater secretion from the left parotid; and the other was ambi-glanded when the secretion was activated by gustatory stimuli, but was right-glanded when mastication movements were used. Thus, 36 of the 40 subjects used in the experiments which involved activation showed the same glandular dominance for activated as they did for inactivated secretion.

Many of the subjects preferred to chew their food more on one side than on the other. Although, as we observed later, glandular exercise may play a small part in increasing the flow from one or the other of the glands, it is apparently not the crucial factor involved. Chewing preference was noted in 25 subjects. Of these there were as many who had a right-sided chewing preference and were left-glanded as there were right-glanded subjects who had a right-sided chewing preference. There were right-glanded subjects who preferred to chew their food on the left side, and there were left-glanded subjects who preferred to chew their food on the right side. There were subjects in each of the three groups (*i.e.*, right-glanded, left-glanded, and ambi-glanded) who reported no chewing preference at all. There were two subjects who had several teeth removed from the left side of the mouth. In both cases chewing on that side was impaired. Both preferred to chew their food mostly on the right side, yet both subjects were left-glanded.

Experiments were then planned to study the effect of exercise upon glandular function. Three students served as subjects for these experiments. The results are tentative, of course, but they do seem to indicate that exercising the weaker of the two glands can increase somewhat the amount of secretion from that gland relative to that from the other. The subjects were instructed to exercise the weaker of their parotids by means of chewing gum for one hour a day between the molar teeth on the side of the mouth in which the weaker gland was located. This exercise was continued every day for four months. At the end of that time the average percentage difference between the stronger and the weaker gland was 11 percent less.

One case was particularly interesting. This subject continued the exercise for more than six months. At the beginning of the experiment he showed an extreme left-glanded dominance. This dominance remained regardless of the nature of the secretogogic or activating agents used. After several weeks of continued exercise periods he reported that he then preferred to chew his meals on the right side. He continued chewing most of his food on that side for more than a year. Despite these continued exercises of his right parotid his left gland still retained a marked superiority at the end of

TABLE II

RELATIONSHIP BETWEEN GLANDEDNESS AND HANDEDNESS, FOOTEDNESS, EYEDNESS, AND EAREDNESS

Subjects	Males			Females			Total Number of Subjects		
	RG	LG	AG	RG	LG	AG	RG	LG	AG
Handedness:									
Right-handed	22	63	7	59	11	17	39	37	13
Left-handed..	4	4	0	5	3	5	5	4	2
Footedness:									
Right-footed..	19	63	8	60	10	18	39	37	13
Left-footed...	5	5	0	6	3	3	5	4	2
Eyedness:									
Right-eyed...	19	52	7	41	10	17	30	31	12
Left-eyed....	5	13	0	20	6	6	14	10	3
Earedness:									
Right-eared..	17	46	8	48	4	12	33	25	10
Left-eared....	8	17	4	20	8	8	14	12	6

RG = right-glanded, LG = left-glanded, AG = ambi-glanded.

a year. It might be mentioned that we had occasion to conduct experiments upon this subject for more than 100 hours during the year, and that at no time did his right parotid gland secrete more than his left when both were activated similarly or when the secretions were obtained during conditions without marked extero-stimulation.

In an effort to determine whether or not a relationship existed between glandedness and any of the functions which in the main show some degree of unilateral dominance, we collected data upon handedness, footedness, eyedness, and earedness on the 78 subjects which were used in this study.

Table II represents the percentages of right-, left-, and ambi-glanded subjects who showed a right or left dominance in the above-mentioned functions. If one bears in mind the data shown in Table I, it will be evident that no significant relationship is indicated between glandedness and these factors. A right-handed or right-eyed individual is about as likely to be right-glanded as left-glanded. But, as might be surmised from what we reported earlier, a right- or left-handed male is more apt to be left-glanded; whereas, a right- or left-handed female is more likely to be right-glanded.

Studies on handedness, eyedness, etc., have revealed that a great majority of the population show a right-sided dominance. From the data collected on glandular dominance, however, we note no such tendency for parotid glandular function. Thus, although 90 percent of our subjects were right-handed, there were only 44 percent who were right-glanded. Though 10 percent of the subjects were left-handed, 41 percent were left-glanded.

Although earlier investigators assumed an identity of reaction from the two parotid glands (**5**, **1**, and others) we have learned that for most subjects the assumption is unwarranted. Until 1936, with only the exception of an occasional experiment (**9**, **10**) the workers who followed Lashley continued to use his method of studying one parotid gland. This technique probably lingered for reasons more of expediency than of choice, since the simultaneous collection and recording of the secretion from both parotids involves some degree of difficulty and practice.

The literature on bilateral glandular studies is very meager. The few studies which have been reported are limited mostly to investigations on lower animals. Moukhine (**7**) claimed from his findings on dogs that the amounts of secretion from the two submaxillary glands are identical. In his studies of the simultaneous functioning of the two parotid glands in dogs, Skliaroff (**8**) reported that the influence of various irritants showed the functioning to be practically identical, with 'insignificant' variations. Montgomery and Stuart (**6**) reported a difference in the secretory rate between the parotids

in their dog. To our knowledge the only evidence of a morphological difference between the two glands has been observed by Bidder in eleven dogs and Heidenhaim in two (3).

It is our guess that the difference in the rate of secretion from the two parotid glands in humans may be in part a function of hypothalamic discharge of unequal intensity from the right and left portions of that region, and in part due to any structural variations which may exist between the two glands.

Summary

1. Although an identity of reaction of the two parotid glands was assumed by earlier investigators, our data indicate a significant difference between the rate of flow from both glands in 69 of the 78 subjects studied.

2. This dominance of one gland over the other was maintained in most subjects for activated as well as inactivated secretions.

3. The data seem to indicate a possible sex variation. Sixty-seven percent of the male subjects were left-glanded; whereas only 14 percent of the female subjects were left-glanded. Twenty-six percent of the males were right-glanded, while 64 percent of the females were right-glanded. Seven percent of the males and 22 percent of the females showed no glandular dominance and were considered to be ambi-glanded.

4. Although bilateral studies on other organs and functions have revealed that a far greater proportion of the population showed a 'right-sided' dominance, we note no such tendency for parotid glandular function. Thus, although 90 percent of our subjects were 'right-sided,' there were only 44 percent who were right-glanded. Though 10 percent of the subjects were 'left-sided,' 41 percent were left-glanded.

5. Exercising the weaker of the two parotids increased the rate of flow from that gland somewhat in three subjects, but that factor was not shown to be the crucial determinant of glandular dominance.

6. Parotid glandular dominance does not seem to be related to handedness, footedness, eyedness, or earedness.

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THE RELATIONSHIP OF CERTAIN ORGANIC FACTORS TO INDIVIDUAL DIFFERENCES IN HUMAN PAROTID SECRETORY RATE

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The study of human parotid secretory reactions has been found to be of considerable value as both a diagnostic aid (**5**, **6**) and as a sensitive and reliable technique in psychosomatic investigations (**1**). Individual differences and variations in parotid reactions have been the object of numerous investigations on the concomitant vegetative changes occurring during affective and mental processes. It has tacitly been assumed in these studies that the differences observed were for the most part of neurogenic or functional origin and that organic factors were of relatively minor importance. This paper is a report of an effort to determine whether or not the factors of weight, height, age, pulse rate, diastolic or systolic blood pressure might be involved in causing the extensive individual differences which have been noted.

The parotid secretions were collected directly from the ducts of the glands by means of modified Lashley suction discs. The technique which we employed has been described in detail in an earlier report (**1**). The results from 123 subjects are incorporated in this study. The subjects were of both sexes; the age range was from 12 to 49 years.

We ranked our subjects according to their total parotid secretory rate obtained while in the normal resting state in which no marked extero-stimulation was applied. From this list we selected the thirteen highest and the thirteen lowest. Thus in one group we had the 'fast-secretors,' and in the other, the 'slow-secretors.' We then made comparisons between their weights, ages, heights, pulse rates, and diastolic and systolic blood pressures. Table I represents the results of these comparisons.

If any of the factors mentioned in the above Table was crucial in determining the individual variations, that factor ought to have been evident in a survey of this type. Obviously none of the factors studied can be regarded as significant. We conclude from these data that if there is an organic factor which affects the variations it will have to be sought elsewhere.

It is interesting to note that in a similar study on gastric secretion (**3**), "No correlation was found between gastric secretion and anatomical measurements (weight, height, chest circumference, chest length, trunk length, and height)." Although it had been believed in the past (**2**) that secretory rate and blood-pressure were intimately related, our studies on

TABLE I

A Comparison of Organic Factors of Individuals Representing the Extremes in Secretory Rate

Factors Studied	'Fastest Secreters'	'Slowest Secreters'
Average weight	141 pounds	140 pounds
Average height	5′ 4″	5′ 4″
Average pulse rate	72 per min.	78 per min.
Average diastolic blood pressure	67 mm Hg	74 mm Hg
Average systolic blood pressure	115 mm Hg	118 mm Hg
Average age	19 years	19 years
Average total secretion per 5 minute period	0.16 cc.	0.04 cc.

humans and those of Moukhine (**4**) on dogs do not give any support to that theory. Moukhine found the secretory rate in his animals to be unassociated with blood pressure changes.

In summary, it may be said that the extreme variations in the rate of inactivated human parotid secretion do not appear to be related to weight, height, age, pulse rate, diastolic or systolic blood pressure. The reasons for the wide range of individual differences in secretory rate have not as yet been definitely ascertained. However, on the basis of recent studies these differences seem to be more a result of 'functional' rather than 'organic' causes. This problem will be discussed in a subsequent publication.

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THE EFFECT OF THE INTER-TRIAL INTERVAL ON THE ACQUISITION, EXTINCTION, AND RECOVERY OF VERBAL EXPECTATIONS [1]

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The results of several recent experiments indicate that certain of the phenomena of conditioned response experiments may be due to the action of two distinct factors which may be designated as expectancy—related to learning, and work-decrement—related to performance.

Humphreys (**10**) has demonstrated similarities between the course of acquisition and extinction of conditioned responses based on reflex reinforcement and those based on verbal expectations. It is to be expected that phenomena determined largely by expectancy in the two types of experiment would show similarities. A relationship between conditioning and expectation of shock has also been demonstrated by Cole (**2**), Cook and Harris (**3**), Mowrer (**12**), and others. There are evidences, however, that this relationship may be limited to certain aspects of the conditioned response experiment (*e.g.*, rate of extinction) (**10**) and may be contingent upon the nature of the stimulus expected and the response being conditioned (**12**). Before definite conclusions as to the rôle of expectancy in the phenomena of conditioning can be drawn, however, the degree of relationship between the two should be more fully investigated.

A second series of experiments points to a relationship between certain phenomena of conditioning and a decrement

[1] This research was carried out in the Department of Psychology, Institute of Human Relations, Yale University. The authors wish to acknowledge the coöperation of Professors D. G. Marquis, L. W. Doob, and R. R. Sears in obtaining subjects for their investigation. The first-named author is indebted to the National Research Council for fellowship funds and to Professor Clark L. Hull who directed his research.

or negative adaptation effect. Hovland (**7**) has demonstrated that the shape of a curve of extinction may be determined by temporal conditions of reinforcement. Massed reinforcement produces a decremental effect which is demonstrated in the initial rate of extinction. Calvin (**1**) and Humphreys (**9**) have shown that such an effect may be found in acquisition curves of conditioning. Earlier evidence of decrement resulting from massed reinforcement had been reported by Hilgard (**5**), Schlosberg (**13**), Wolfe (**14**), and others.

The operation both of decremental and of expectation factors is inferred by Ellson (**4**) in order to explain the results of a study of spontaneous recovery as a function of time. Recovery was demonstrated both for amplitude and for rate of extinction of the GSR; recovery was progressive, however, only for the former measure. Presumably the amplitude of the response is more subject to the adaptation produced by repeated reinforcement than is rate of extinction. Conversely, rate of extinction of the response may be a more sensitive indicator of expectancy than is amplitude (**8**).

Since the work-decrement factor would presumably be at a minimum for a verbal choice, the present study of the expectancy factor utilizes verbal behavior under circumstances paralleling as closely as possible those of a conditioning experiment. The expectations are set up by repeated pairing of two stimuli. Following the presentation of the first stimulus on each trial, the frequency of the verbally expressed expectation of the second stimulus is measured. Extinction is then obtained by regular omission of the second light, and spontaneous recovery is tested by a second extinction series which follows the first after a given interval. In the customary conditioning experiment the response is made or not made on a given trial, but the instructions in the present experiment determine that a response and a choice, either positive or negative, will be made on every trial.

Apparatus and Procedure

An apparatus similar to that used earlier by Humphreys (**10**) was constructed. Two lights, one red and one green, were mounted on the right and left sides of a square, vertical board. These lights were controlled by switches placed behind the board and

out of sight of the subjects. The latter were told that the green light would always be turned on and would sometimes be followed by the red light. They were further instructed to anticipate the presence or absence of the red light by writing appropriate symbols on a mimeographed data sheet. Their anticipations of the occurrence of the red light served as the 'conditioned responses.'

The standard preliminary instructions given were as follows:

> "In this experiment you are to anticipate the turning on of the right-hand (red) light. The left-hand (green) light will be turned on at regular intervals. Sometimes this will be followed by the red light, sometimes not. When the green light goes on, you are to mark down a cross if you expect the red light to follow, a zero if you do not expect it to follow. Do not take time to think. Mark a cross or zero immediately—as soon as the green light goes on. Do not leave any blanks. Mark from left to right, starting with the top line."

At the start of the second extinction period additional instructions were necessary:

> "We are now ready to start a new series. Follow the same instructions as before: mark down a cross, if you expect the red light to follow the green, a zero if you do not expect it to follow."

Subjects were from three undergraduate psychology classes of Yale University numbering 162, 50, and 67 students, respectively. Since it was possible to conduct the experiment in large groups, subjects were seated in their usual lecture rooms. With the apparatus resting on a table on the platform at the front of the room, the colors of the lights and their spatial disparity could easily be seen by all of the subjects.

The experimental conditions for the three groups follow:

Group I. Trials occurred at a *5-second rate*. Twenty-four paired presentations of the two lights were followed immediately by 24 'extinction' trials of the green light alone, and after a *30-minute recovery interval* the green light was again presented alone for 20 trials.

Group II. Trials occurred at a *10-second rate*. *The recovery interval was 4 minutes.* Otherwise, conditions were the same as for Group I, *i.e.*, 24 acquisition, 24 first extinction, and 20 second extinction trials.

Group III. Trials occurred at a *20-second rate*. Twenty-four acquisition trials were followed by 15 extinction trials (no recovery test with this group).

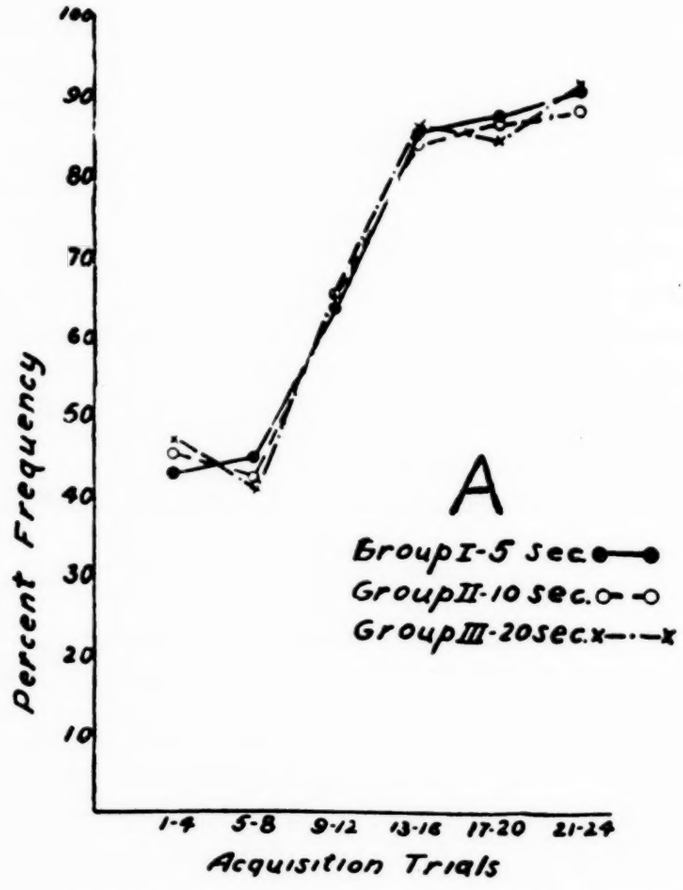
Although time intervals between trials differed in the three groups, the interval between the conditioned (green) stimulus light and the unconditioned (red) stimulus light was maintained at approximately 3 seconds. This interval was long enough for the written anticipations of the red light to occur.

Results

The results are presented graphically in the accompanying figures. The amount of expectation is plotted in terms of percent frequency, that is, the ratio of the number of anticipations of the red light on any trial to the total possible number. The acquisition curves are plotted for groups of 4 trials and the extinction curves for single trials.[2]

[2] Only the first six trials are graphed in the extinction curve. The remaining trials form a fairly smooth extension of the curve consistently near zero.

The acquisition curves (graph A) closely resemble one previously published (**10**) for acquisition of verbal expectations. The rise in frequency is apparently more rapid than is usually found for reflex reinforced responses. The drop in frequency during the early trials gives the curves the S-shape frequently reported for reflex reinforced responses (**6**). In the present case this phenomenon of initial drop is probably

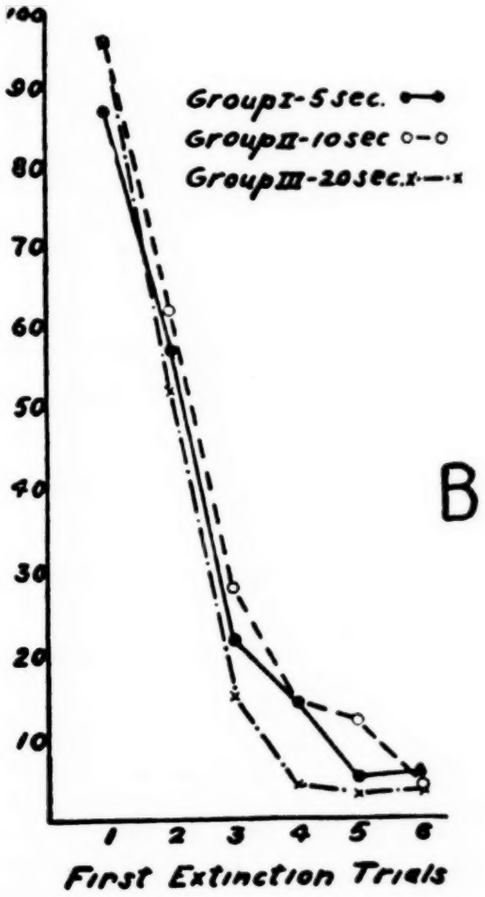


GRAPH A. Acquisition of verbal expectations. Trials are grouped in fours for facility in presentation. The three curves start near the expected chance level and have the S-shape frequently reported for reflex reinforced responses. There is little difference in performance among the three groups of subjects.

best explained by the set which results from the instructions and the subjects' past experience with chance series. It will be recalled that the subjects were told at the start that the red light would sometimes follow the green light *and sometimes not.* After the red light had regularly followed the green in the first trials there were a considerable number of reversals of response

from × to o for several consecutive trials. It is presumed that the instructions had started the subjects off with a predominant expectation that a chance series was being run. This quickly gave way to regular expectations of the red light.

There are no differences in rate of acquisition resulting from variation of the inter-trial interval. It is, therefore,



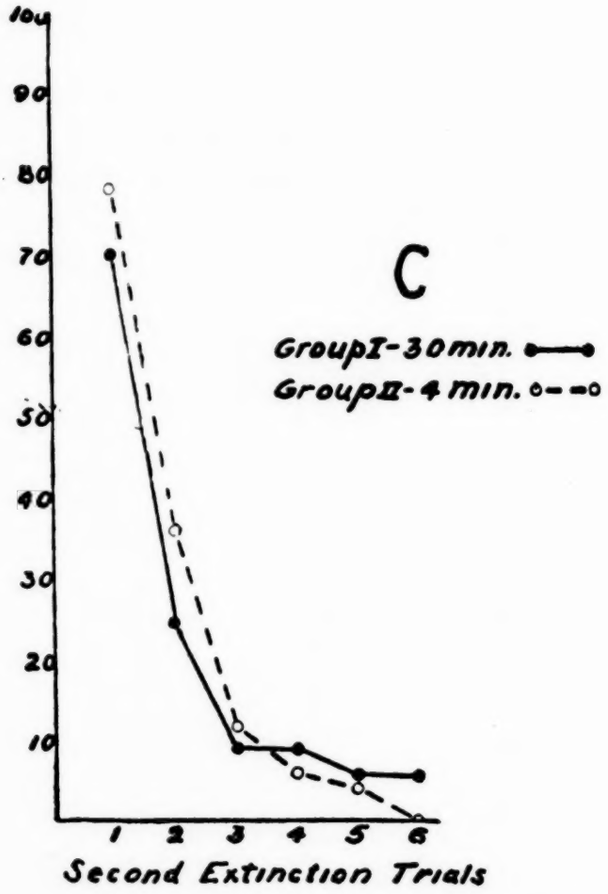
GRAPH B. First extinction of verbal expectations. Only the first six trials are shown; the remaining trials form fairly smooth extensions of the curves consistently near zero. The rapid negative acceleration characteristic of the extinction of reflex reinforced responses is exhibited. There is little difference in performance among the three groups of subjects.

concluded that within the time limits here employed spaced practice is of no advantage in the acquisition of verbal expectations.

The extinction curves (graph B) also resemble those resulting from non-reinforcement of reflex reinforced CR's. This is particularly true with respect to the great rapidity of extinc-

tion. In the present study the drop from almost 100 percent expectation to very nearly zero takes place in a few trials. It is clear, in addition, that the interval between trials is of no significance in the determination of the rate of extinction.

When the rate of extinction is compared with the rate of acquisition, it appears that the change from a regular expecta-



GRAPH C. Second extinction of verbal expectations. Only the first six trials are shown; the remaining trials form fairly smooth extensions of the curves consistently near zero. There is little apparent relationship between second extinction performance and the recovery interval.

tion to its negate is much more readily accomplished than the change from a chance expectation to a regular one. This confirms the previous findings of Humphreys with respect both to verbal expectations (**10**) and conditioned eyelid responses (**8**).

In a study of the spontaneous recovery of the galvanic skin response, Ellson (**4**) found progressive increase of amplitude

during the interval following extinction, but no progressive recovery of resistance to extinction. In an hypothesis which accounted for these results, he made the assumption that expectation (in this case of a shock) did not show a progressive recovery with time. The data obtained in the second extinction of the present experiment tend to verify that assumption. Although there was approximately 70 percent recovery in terms of frequency, there was no evidence of *progressive* recovery of the expectations. There is no greater initial percentage of expectation of the red light for the group given a 30-minute recovery interval than for the group given a four-minute interval; in fact the 30-minute group shows slightly less recovery.[3] The difference is not statistically reliable, however. The curves for this second extinction for the two groups are also very similar (graph C), again indicating that the 'resistance to extinction' of the verbal expectations does not show progressive recovery within the limits used. These findings suggest that the progressive nature of spontaneous recovery in conditioning experiments is perhaps due to decremental factors and is not an actual learning phenomenon.

Summary

Verbal expectations of three groups of 152, 50, and 67 college students were studied under the following conditions:

Group I—24 acquisition, 24 first extinction, and 20 second extinction trials were given at a 5-second rate. A 30-minute recovery period intervened between first and second extinction.

Group II—conditions were the same as for Group I except trials occurred at a 10-second rate and the recovery interval was 4 minutes.

Group III—24 acquisition and 15 extinction trials were given at a 20-second rate. Recovery was not tested.

From the results it can be concluded: (1) within the time limits here employed spaced practice is of no advantage in

[3] It should be noted that the two groups, while comparable in terms of performance during acquisition and first extinction, are not comparable in terms of the interval between trials. The results would thus be open to criticism on the latter score except that the interval between trials is apparently a non-operative or at least a very weak factor.

either acquisition or extinction of verbal expectations; (2) spontaneous recovery of verbal expectations occurs, but within the limits of the time intervals used, no evidence of *progressive* recovery is obtained. It is suggested that both the progressive character of spontaneous recovery and the beneficial effects of spaced practice in conditioning experiments are due to decremental rather than expectancy factors.

(Manuscript received January 20, 1940)

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THE PERCEPTION OF SIZE IN BINOCULAR, MONOCULAR AND PIN-HOLE VISION

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In an earlier article, 'Visual size constancy as a function of convergence,' [1] I cited a study by Maier [2] as an example of lack of proper consideration of convergence as a factor in the perception of size. Maier's subjects were required to reproduce with binocular vision—*i.e.* with the factor of convergence involved—the perceived size of an aperture viewed through a pinhole. The reproductions were significantly smaller than the standard. This appeared to me to be attributable to the fact that the pinhole vision used was monocular vision, and that a comparison of monocular and binocular vision might show much the same difference. The point of my discussion as indicated by the title of this earlier article was not to explain the illusion of size in pinhole vision. In a subsequent conversation with me Dr. Maier expressed the belief that the amount of difference between pinhole size estimates and the standard was too great to be accounted for in the manner I had suggested.

The problem is here subjected to experimental solution. What are the perceived sizes in pinhole vision as compared with monocular and with binocular vision? In the present article I wish to report findings similar to Maier's in pinhole vision, and further to report a comparison of monocular and binocular perception of size, and an interpretation of the facts.

Apparatus.—Two boxes were built four feet in length and tapered in shape from fourteen inches square at one end to eight inches at the other. The eye pieces were placed in the small end of each box and a frosted glass window, frosted side out, was placed in the larger end. The boxes were lined with black velvet. To obtain a clear cut outline the apertures were cut in shim brass and placed against the frosted surface of the glass. Over the brass was placed heavy blue glass to force a closer contact of the

[1] Hermans, T. G., Visual size constancy as a function of convergence, *J. exper. Psych.*, 1937, **21**, 145–161.

[2] Maier, N. R. F., The illusion of size in pinhole vision, *Amer. J. Psychol.*, 1929, **41**, 291–295.

brass with the frosted glass; this also reduced the intensity of illumination on the outside of the boxes so that the subjects could see nothing but the lighted aperture. The standard aperture was a 100 millimeter square so placed that the diagonals of the square were vertical and horizontal. The adjustable aperture for the other box was made by cutting right-angle V's in the sides of two sheets of shim brass. By sliding the open sides of the V's together a variable aperture similar in shape to the standard was formed. The movement of the brass sheets was accomplished by suspending them at their upper edge from steel bars driven in opposition by rack and gear. The gear was fastened to one end of a steel rod which ran the length of the box with a knob at the other end. By turning the knob the subjects could vary the size of the aperture from a 200 mm square to practically zero. The blue glass on the outside of the brass served the purposes as indicated above during the manipulation of the aperture by the subjects and also prevented the brass sheets from buckling.

Conditions of Observations.—The subjects were told that the purpose of the experiment was to determine the apparent size of the illuminated square under certain conditions; that they were to reproduce the size as it appeared to them; that there was no correct size; that each one of their judgments was right. They were instructed to adjust the aperture to the point where it seemed the same size, with no shifting of it back and forth after that size had been reached. The reproductions of the perceived size of the standard were all made with binocular vision. Half the subjects observed the standard square first with monocular pinhole vision and later with unobstructed monocular vision. This order was reversed for the other half. Lastly all subjects observed the standard square binocularly. Each subject made ten judgments with pinhole vision, ten with monocular, and ten with binocular vision. Within the series of ten judgments for each condition half of the adjustments of the variable aperture were started with the aperture opened to a maximum size, and half were started with the aperture shut to near the minimum size. The sizes of the aperture as adjusted were measured and recorded in millimeters.

One hundred subjects were used on the experiment, each making thirty judgments. Thus the data collected consisted of three thousand judgments. The subjects were for the most part elementary psychology students.

Statistical Analysis of the Results.—The individual's averages of the ten judgments for each of the three conditions were regarded as the individual's size estimates for the three conditions. The following table summarizes the data obtained. The unit of measure is 1 mm.

	Mean	Sigma (dist.)	Sigma (mean) $N = 100$	Difference of Means	Sigma of Diff. of means	Critical Ratio
Pinhole vision.....	67.25	23.05	2.305	25.45	1.62	15.7
Monocular vision...	93.7	14.30	1.43			
Binocular vision....	104.76	6.54	.654	11.06	1.19	9.2
	(Comparison of Pin-hole and Binocular Vision)			37.51	1.8	21.3

r (pin.-mon.) = .73 ± .03 r (mon.-bin.) = .56 ± .04 r (pin.-bin.) = .48 ± .05

Discussion and Meaning of the Results.—These data support Maier's findings that in pinhole vision the perceived size is significantly smaller than in binocular vision. They also show a very significant difference between the estimates of size in binocular vision and the estimates of size in monocular vision; the estimates of size in monocular vision as compared with pinhole vision are even more significant; the significance of the difference in means of binocular estimates and pinhole estimates is very great. It is obvious that my suggestion, that the illusion of size in pinhole vision is due simply to the fact that pinhole vision is monocular vision, is not validated in fact.

I must admit here to a heinous influence of my bias in the selection of the size of the pinhole for my apparatus. Maier used five different sizes of pinholes varying from .03 to .09 of an inch in diameter. He reported the illusion to be present with all five, but that "there was a general tendency for a slightly greater reduction for smaller pinholes, *i.e.* a greater illusion." I used a pinhole slightly smaller (.086 in) than his largest, ostensibly to facilitate the subjects' ready detection of the standard aperture. Had I not obtained the very significant difference between monocular and pinhole size estimates that I did, I would have been obligated to use smaller pinholes to test the validity of Maier's contention.

Maier's explanation, however, is not satisfactory. He concludes "that the 'illusion' is largely due to a reduced retinal image on account of combination of near accommodation with the pinhole between the object and the dioptric system." First, there is no evidence that the retinal image is reduced in size in pinhole vision. Closing the aperture in a camera does not reduce the size of the image on the film. Further, one can demonstrate that the retinal image is not reduced by obtaining an after image while fixating an object through a pinhole and then without the pinhole, projecting the after image adjacent to the object (distance constant); the object and the after image appear to be equal in size. Second, there is no evidence that with pinhole vision, accommodation is adjusted for near vision. If anything, no particular accommodative set is necessary. Maier suggests this in one place but does

not follow it up; he says, "It is possible to get a clear image of an object through a lens, though the lens be out of focus, with the aid of a small aperture. Thus the pinhole serves to give a clear image no matter what the accommodation is, and the retinal image is made smaller when the lens of the eye is accommodated for some point nearer than the object observed." I demonstrated to my own satisfaction and to that of one colleague that in pinhole vision no accommodation is necessary. With a set of oculist's lenses and a pinhole .028 of an inch in diameter, I found I could get a clear image by use of the pinhole with lenses as diverse as plus 20 and minus 20 diopters. Obviously, no accommodation is required for pinhole vision.

Another point or two in Maier's report requires comment here. He cites Helmholtz as stating that with the object very close, it may appear even larger in pinhole vision. Maier says of his own observers, "It was also found that as O moves closer to the object there is a point of no-reduction in size of the object-light when observed through a pin-hole. This distance is generally about 2 m from the object." My observers were four feet from the object—somewhat less than 2 m. Further he suggests that without accommodation the illusion disappears, in support of the point that it is near accommodation with pinhole that produces the illusion. "Os under atropine (and thus without accommodation) were also tested. A far-sighted O had little or no reduction in the size of the object-light observed through the pinhole." From the foregoing table of my results it is indicated as very likely, by the sizes of the standard deviations and the correlation of pinhole and binocular size estimates, that some of my subjects (without atropine) had little or no reduction in the size as observed through the pinhole. He supposedly demonstrates that the retinal image of the object seen through the pinhole is made smaller when the other eye is accommodated for a point closer than the object seen through the pinhole. This, it would seem, is simply a change in the apparent size produced by a change in convergence, not a change in size of the retinal image.

Conclusion.—The importance of muscular factors in the

perception of size is demonstrated again in the present experiment. When the standard is observed with binocular vision, *i.e.* with cues from bi-retinal stimulation, convergence, and binocular accommodation, the reproductions of size (with the same cues present) showed a close agreement with the standard. When the standard is observed with pinhole vision, *i.e.* with monocular retinal stimulation present, but with convergence and accommodation eliminated or of no constant amount, the reproductions of size with binocular vision (with binocular retinal stimulation, convergence, and binocular accommodation present) showed an even greater and more significant difference from the binocular and monocular estimates of size. Just why the binocular size estimates averaged 104.76, with sigma of M. 6.54, rather than nearer to the 100 mm size that one would expect, was not determined. However, a likely explanation is that any deviation from an exact binocular fixation at the distance of four feet while viewing the standard would tend to be a fixation adjustment for some greater distance, as if the subject were looking through the aperture window. If this were the case, the perceived size of the aperture would increase. While reproducing the square the eye is more likely to fixate the moving margin of the aperture so that both monocular and binocular accommodation will be more nearly correct for the four foot distance.

In monocular vision the convergence factor, if not eliminated, is at least not held constant; in pinhole vision this is true of both convergence and accommodation. The lack of constancy or control of these factors is indicated by greater standard deviations of average estimates in monocular and pinhole vision than in binocular vision, and this variability is in inverse relation to the amount of control. Whether the unnecessary muscle activities in monocular and pinhole vision are eliminated or not is not known, but they do not furnish under such conditions reliable cues for size perception. Size perception is most accurate and reliable when cues from monocular accommodation of both eyes and convergence are present, these being the conditions under which we have learned to perceive size.

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AN IMPROVED AMPLIFIER FOR ELECTRO-ENCEPHALOGRAPHY

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Since Matthews introduced the balanced amplifier for this work, few improvements have been made in the construction of the amplifiers. Still the balanced battery operated amplifier is an instrument far from perfection. The batteries need constant care and their testing is time-consuming work. It was felt that an A.C. operated device would be much more satisfactory and simpler to operate. In order to build such an amplifier we began by setting up the requirements it has to meet. In agreement with Rudolph Ottenthal we considered the brain as a constant voltage generator of about 50 microvolts, with an internal impedance of about 20,000 ohms average.

I. OUTPUT

The output of the amplifier is matched to the recording device, in this case a Western Union Undulator. The impedance of the one used is 800 ohms, and for full deflection (16 mm), 17.5 volts are required.

II. FREQUENCY RANGE

It is quite true that the amplifier used for research should have a frequency range from zero to about 10,000 cycles per second. However, for most of the routine work, the frequencies lie below 45 cycles per second. Our old galvanometer, tuned to about 30 cycles per second, behaves above this frequency as a true velocity device; *i.e.*, the amplitude decreases at the rate of 12 decibels per octave. Taking both facts into consideration, we decided to restrict the frequency range of the amplifier by the use of tuned filters from 4/10 to 48 cycles. This reduction will also reduce any stray

pick-up, mainly the 60 cycle field so often encountered in this type of work.

III. Gain

The gain of the amplifier is set by the above mentioned requirements and can best be expressed in power gain.

Formula I:

$$10 \log \frac{P_1}{P_2} = 10 \log \frac{\frac{E_1^2}{R_1}}{\frac{E_2^2}{R_2}} = 10 \log \frac{\frac{(17.5)^2}{800}}{\frac{(50 \times 10^{-6})^2}{20 \times 10^3}} = 125.5 \text{ db.}$$

P_1 = output power,
P_2 = input power.

In order to obtain an output voltage of 17.5 volts with an input of 50 microvolts, a gain of about 126 decibels is required.

To be able to record abnormal conditions, where the voltage may reach a peak of 500 microvolts, or ten times the normal voltage, a suitable control to vary the gain of the amplifier is needed. Another requirement is stable operation under varying line of supply voltages.

IV. Power Source

For practical purposes, such an amplifier should be A.C. operated, because the operation and maintenance of A.C. operated amplifiers is much simpler than battery operated ones. Therefore, great stress has been laid in the design to fulfill this requirement.

V. Size

For practical use the size should be also limited. Frequently it is very desirable and sometimes necessary to bring the instrument to the patient. A bulky, battery operated, rack mounted instrument cannot be transported to the bedside of the patient. Emphasis should be laid on reduction of weight and size, in order to be a portable instrument.

VI. Summary of Requirements

1. The output impedance should match the recording galvanometer.

2. The frequency range should be restricted in order to keep the apparatus free from pick-up of outside interference.

3. The available gain of the amplifier ought to be sufficient to record abnormal, as well as normal, voltages.

4. The ease of operation and maintenance calls for an A.C. operated apparatus.

5. The apparatus should be kept as compact and light as possible to make it practical to carry it to the patient.

Design Considerations

For practical reasons, a resistance capacity coupled push-pull amplifier was chosen. In recent literature, descriptions of several such amplifiers have been published, and describing again the entire circuit would mean duplication. Therefore only those circuits that seem new in conjunction with this type of equipment are described in this paper.

A. Power Supply

The average set of batteries (270 volts) have an internal resistance of about thirty ohms. In order to get the same results, the power supply should have the same internal impedance or preferably less. In a conventional design, the impedance of the power supply, as seen by the sink, is a function of the reactance of the condenser in the output of the filter and, therefore, of frequency.

In order that the impedance of the amplifier is as low as a set of batteries, the size of the condenser is determined by the following formula.

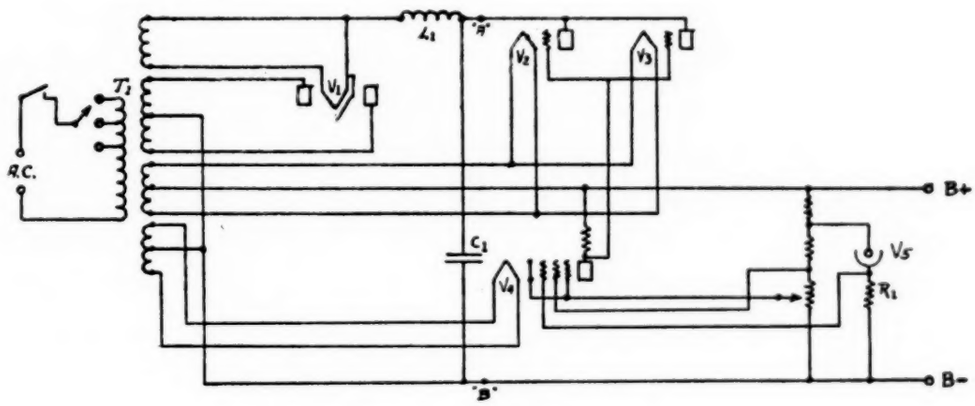
Formula II:

$$C = \frac{1}{\omega X_c} = \frac{1}{(2 \times 3.14 \times 1) \times 30} = 5300 \text{ microfarads.}$$

C = capacity in farads,
$\omega = 2\pi f$,
X_c = reactance of condenser at the desired frequency,
f = desired frequency.

This value, even in the days of electrolytic condensers, cannot be housed in portable equipment. But, by following

the ordinary filter design in a power supply by a D.C. amplifier of ample power carrying capacity and amplification, the voltage output of this power supply can be held constant irrespective of load variation. The dynamic impedance is expressed as $\Delta e/\Delta i$ and can be held below five ohms. If no reactive components are used in the regulating circuit, then the output impedance will not be a function of frequency. The circuit of such a power supply is shown in Fig. 1. The



Minimum of Inductance L'
Formula IIa

$$\frac{\omega L'}{R_L} \geq \frac{2f}{E_{dc}}$$

FIG. 1. V_1 = R.C.A. 83V, $V_{2,3}$ = R.C.A. 2A3, V_4 = R.C.A. 1852, V_5 = R.C.A. VR 130, R_1 = 9000,~ C_1 = 8 MFD, $\omega = 2\pi f$, L = inductance in henry, R_L = load connected to power supply, $2f$ = the ripple frequency of the power supply. In the above case twice the line frequency. E_{dc} = output voltage. Load voltage as measured across points A and B.

transformer (T_1), the rectifier tube (V_1), the filter (L_1C_1) comprise a power supply of excellent regulation with an output of about 520 volts at full load. The gain of the control amplifier can best be expressed in mutual conductance, which is about 400,000 micro-mhos, in other words, the output impedance is $1/G_M = 1/.4$ or 2.5 ohms.

At first glance, the filter seems small, but if formula IIa is fulfilled and in conjunction with the control amplifier the ripple component in the output is less than -40.0 decibels relative to 1.73 volts, sufficiently low to be negligible. The useful output voltage of the unit is 300 volts at 160 M.A., and

is held within 0.2 volts from no to full load ($\Delta e/\Delta i$). A.C. line variations to input of the power unit should be held within 12 percent; greater line voltage changes may cause instability in the output. This power unit also delivers current to the electro-magnet of the ink-writing recorder. This current has to be held constant, since the deflection of the pen is a direct function of flux density which in turn is a function of current, as the magnetic circuit is not saturated.

B. Oscillations in Voltage Amplifier

With a total amplification of approximately 100 decibels distributed over three stages, one has to keep in mind that only one hundredth thousandth part of the output voltage has to be fed back into the input; *i.e.*, in the right phase relation, to start and maintain self-oscillations. In the frequency band the amplifier covers, electrostatic coupling is possible only under the most uncommon conditions. The main source of trouble lies in common impedances; therefore, decoupling of the first stage is absolutely essential. Two resistance capacity filters in tandem, with a time constant of about five seconds each, should be sufficient. The last two stages of the voltage amplifier, if properly designed, so that both are identical in current relation, do not show any tendency to go into self-oscillations. In the amplifier built in our laboratory, we increased the gain to 124 decibels and, after it was found stable, we applied 24 decibels of negative feedback over the first three stages of the amplifier. In this way we reduced the noise output to such a degree that, while using ordinary radio vacuum tubes of the R.C.A. 77 type, we were still able to measure as low as 1.5 microvolts. About one out of six type 77 tubes was quiet enough to be used in the first stage under the above mentioned conditions. To reduce further the noise output and to make the amplifier less susceptible to 60 cycle pick-up, we coupled the voltage amplifier to the main amplifier through a one and a half section filter, one section constant "*K*" followed by a half "*M*" section, which has its infinity suppression point at sixty cycles. This gave us an attenuation loss of about 58 decibels at sixty and 35 decibels at one

hundred twenty cycles and less than 1.0 decibels over the entire pass band (0.4–45 cycles).

C. Power Amplifier

Figure 2 is the schematic diagram of the power amplifier. The recorder is placed where R_L is located. The four power tubes work as four arms of a bridge and therefore no current flows through the load unless the bridge is unbalanced by an A.C. signal. The in-phase signals, such as variations in supply voltage, will not appear across the load. The gain of V_5 and V_6 has to be adjusted to the same as that of the power tubes

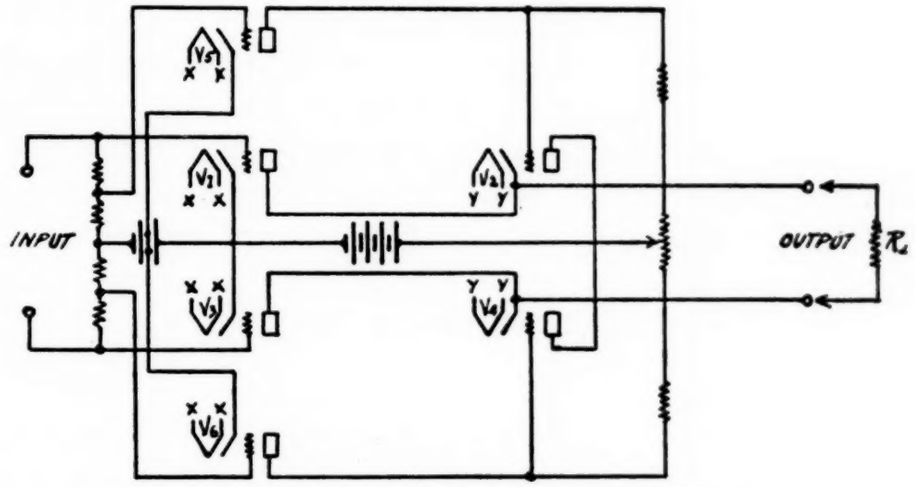


FIG. 2. $V_{1,2,3,4}$ = R.C.A. 2A3, $V_{5,6}$ = R.C.A. 56.

in order to get distortionless amplification. With 710 volts as plate supply, an output of 125 volts across 800 ohms can be realized, with less than 5 percent distortion, enough to drive almost any ink-writing galvanometer.

The power supply is of conventional design. Good regulation should be the paramount design factor, not good filtering, because the gain of the amplifier is low (26.0 decibels) and, as said before, in phase voltages cancel automatically. The rectifier tubes used in this supply were R.C.A. 866 A tubes.

D. Controls

1. Power switch operating both units.

2. An eleven stop volume control located between the voltage amplifier and the filter in steps of 4 decibels each (which gives a 160 to 1 volt range).

3. A test voltage—approximately 40 microvolts—to give 80 percent deflection with the amplifier on full gain.

4. A galvanometer, similar to the R.C.A. recording galvanometer, focused onto a ground glass is used as an indicator. This type was necessary as most other types were found to be inadequate.

5. A plate metering switch to indicate in percent the current in each pair of tubes and in the last two positions the plate voltage of each of the power units.

6. Plate voltage adjustment for the voltage amplifier.

E. Filaments

All filament leads are shielded. With proper placement of the filament leads and parts plus the 48 cycle low pass filter, it is possible to use alternating current on the heaters of all tubes including the first stage. In series with the filaments in the first two stages in the voltage amplifier are current regulating lamps, to keep the temperature of these filaments constant. These current regulating lamps are housed in the power supply cabinet.

F. Mechanical Description

The voltage amplifier is a resistance capacity coupled three-stage push-pull amplifier. The main amplifier is a two-stage push-pull direct coupled amplifier. Both amplifiers and the filter are built in one case (12 tubes). This unit is connected to the power supplies by cables and all controls except the plate voltage adjustment are located on the amplifier chassis. The input and output of the amplifiers are of the shielded plug type. The weight of the unit complete and ready to operate, less recorder, is seventy-nine pounds. Not exactly portable, but a great improvement over the old type battery operated units.

Summary

The equipment built in our laboratory was found to meet and exceed all requirements. It is easy to transport and will operate under most adverse conditions.

Tests can be duplicated from week to week. The only troubles thus far encountered have been selection of tubes and inadequate frequency response of the ink-writing galvanometer. A new galvanometer is now under construction to meet our needs.

Complete electrical specification follows:

Gain.....86 to 130 decibels variable in steps of 4 decibels.
Frequency range.....4/10 to 45 cps. ± 1 decibel.
Stability.....± 1 decibel with line voltage fluctuation of ± 10 percent.
Noise output.....Less than −30 decibels/1.73 volts.
Power output.....10 watts into 800 ohms with less than 2 percent distortion.
Power consumption.....464 watts at 115 volts 60 cycles.

This research was partially conducted at the Psychology Department of the University of Southern California and partially at the Electro-Encephalograph Laboratory of the Cedars of Lebanon Hospital in Los Angeles.

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